UDC 004.9:621.3:658.5
DOI: 10.15587/1729-4061.2025.336641

BUILDING A CONSOLIDATED MODEL OF DIGITAL COHERENCE FOR MANAGING THE INFORMATION POTENTIAL AT POWER ENTERPRISES

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This study's object is the process of managing the information potential of energy enterprises under the conditions of digital coherence. The task addressed is to build a consolidated model of digital coherence, which would enable the functioning of digital, management, and information elements of the enterprise, promote the integrated development of information potential, and increase the adaptability of energy enterprises to digitalization.

A consolidated model of digital coherence has been constructed and substantiated as a basic methodological basis for effective management of the information potential of energy enterprises. Digital coherence is considered as an integrative characteristic that ensures the consistency of digital resources, technologies, processes, and management practices within the strategic, operational, and analytical levels of an energy enterprise.

The proposed model combines elements of digital strategy, digital platforms, innovative technologies, and digital culture into a single coherent system, which makes it possible to increase stability, adaptability, and management efficiency under the conditions of digital transformation.

A system of quantitative criteria and indicators for assessing digital coherence has been designed, implemented in the form of an integrated index. The model has been tested on the example of the Zaporizhzhia Power Plant, which made it possible to track the dynamics of digital integration and the impact of crisis events (in particular, wartime) on the level of information potential in 2012–2024.

The digital maturity of the power plant demonstrates regressive dynamics: the integrated digital coherence index decreased from 0.386 (2021) to 0.260 (2024), which indicates a degradation of the level of integration of digital solutions into the management processes of the enterprise

Keywords: integrated digital coherence index, digital coherence of energy enterprises, digital transformation management, digital consistency of management decisions

Received 13.06.2025
Received in revised form 11.07.2025
Accepted 30.07.2025
Published 27.08.2025

How to Cite: *Prokhorova, V., Budanov, O., Budanov, M., Slastianykova, K. (2025). Building a consolidated model of digital coherence for managing the information potential at power enterprises. Eastern-European Journal of Enterprise Technologies, 4 (13 (136)), 58–69. https://doi.org/10.15587/1729-4061.2025.336641*

1. Introduction

In today's digital economy, energy companies are under pressure from the need for deep organizational and technological transformation. The rapid development of digital technologies, the intellectualization of management systems, increased requirements for energy efficiency, cybersecurity, and adaptability determine the need for new approaches to managing information potential (IP). Information potential is considered as a strategic integrated resource that combines information technologies, digital infrastructure, management structure, personnel competencies, and organizational culture, and determines the ability of an enterprise to adapt to a dynamic digital external environment.

Information potential is becoming not only a tool for ensuring operational efficiency but also the basis for the competitiveness, innovation, and sustainability of energy companies. However, effective use of information potential is possible only under the conditions of achieving digital coherence – the integrated, coordinated functioning of the digital, information, and management components of the enterprise. The concepts of digital strategy, platform solutions, innovative technologies, and digital culture should be coordinated in a single information potential management system to enable the sustainable development of an energy enterprise.

Despite the growing attention to digital transformation, a number of problems remain unresolved. First, the implementation of digital solutions is fragmented, which leads to the dispersion of information resources and low compatibility of digital platforms. Second, the methodologies for assessing information potential are not sufficiently unified and do not take into account factors such as digital maturity, culture, and external risks, including cyber threats. Third, the challenges of cybersecurity and data protection, which directly affect the continuity of energy supply, remain relevant. Finally, a key barrier is the lack of digital competencies of personnel and a weak level of digital culture in organizations. All this creates an objective need for a scientifically based, adaptive model of digital coherence, which would allow for holistic management of information potential in the context of digital transformation.

The relevance of this issue relates to the growing complexity of the information infrastructure, the need to increase the digital coherence of business processes, technological instability, cybersecurity threats, as well as increased competition in the energy sector. The lack of a holistic approach to digital coherence leads to a decrease in management efficiency, loss of information resources, and limitations in the strategic development of energy enterprises. In this context, the construction of a consolidated model of digital coherence is not only a scientific but also a practical step towards increasing the adaptability and resilience of energy enterprises in the digital environment.

2. Literature review and problem statement

In work [1], the basic theoretical concepts of digital transformation in the energy sector are investigated. The key components of information potential are highlighted – digital platforms, IT infrastructure, and personnel competencies, emphasizing the role of digital strategy models as the basis for effective management of energy enterprises. The need for comprehensive integration of digital technologies to achieve digital coherence is indicated. However, the issues of quantitative measurement and diagnostics of the effectiveness of information potential management remain unresolved, in particular, there are no adaptive methods capable of detecting imbalances in information flows and promptly responding to digital challenges. The likely reason is insufficient empirical verification of the proposed theoretical provisions, limited involvement of applied analytics tools, as well as the lack of generalized models suitable for practical application under the conditions of digital coherence of energy enterprises.

In [2], the study focuses on the influence of digital culture on information potential management. It is proven that without a formed digital culture, the adaptation of technological innovations is ineffective. Methodological recommendations are proposed for increasing the digital literacy of personnel and forming a corporate culture focused on innovation. However, the issues of the complex relationship between the level of digital culture and the effectiveness of information potential management at different stages of the digital transformation of enterprises remain unresolved. The likely reason is the limitation of the sample (mainly Chinese companies), the lack of cross-sector comparison, as well as the lack of research into the impact of external factors (economic environment, state digital policy, etc.) on the transformation of digital culture.

In paper [3], a system of quantitative indicators is proposed to assess the digital coherence of an energy enterprise. An integrated index is defined, which includes technical, organizational, and strategic parameters, which makes it possible to track the dynamics of digital integration using the example of real enterprises. However, the issues of ensuring the flexibility of this assessment system for different types of enterprises, as well as the integration of digital coherence indicators with indicators of information potential management efficiency, remained unresolved. The likely reason is the focus of the study on only one object of observation, the insufficient level of technological detail of the analytical tools, as well as the limited coverage of the specificity of information processes under the conditions of digital hybridity of the structure of energy enterprises.

Work [4] reports analysis of the implementation of advanced technologies – blockchain, artificial intelligence, Internet of Things (IoT), big data – in the processes of managing the information potential of enterprises. It is emphasized that the use of such technologies requires updating management models to enable the flexibility and adaptability of enterprises. However, the issues of developing integrated management models that take into account the specificity of the implementation of digital technologies in various segments of the energy industry, as well as assessing the risks associated with the security of new technological solutions, remain unresolved. The likely reason is the general nature of the cited review without a deep systematization of risks, the lack of applied tools for quantitative analysis of the effectiveness of digital solutions, as well as limited attention to the implementation of innovations in production and information settings.

Study [5] considers the issues of ensuring cybersecurity in the context of the digital transformation of energy enterprises. The need to include cyber protection in the digital transformation model as an integrated element of information potential management is emphasized. However, the issues of formalizing practical mechanisms for integrating cybersecurity into information potential management systems, in particular taking into account different levels of threats, types of digital infrastructure and the degree of data criticality, remain unresolved. The likely reason is insufficient specification of management models in terms of cyber protection, as well as a fragmented approach to assessing the risks of the digital environment within the information potential.

Paper [6] examines in detail the role of digital platforms as an integration framework that unites heterogeneous information systems and ensures scalability and flexibility of management processes. It is emphasized that digital platforms make it possible to optimize the processing of large amounts of data, which is critical for operational decision-making in the energy sector. However, the issues of adapting the proposed models to the conditions of large energy enterprises with a branched structure, as well as the integration of digital platforms with strategic information potential management systems, remain unresolved. The likely reason is the focus of the study mainly on European small and medium-sized enterprises, the limited empirical coverage, as well as the insufficient development of the methodology for applying digital platforms in multi-level organizational structures of the energy sector.

Study [7] reports the construction of models that take into account the dynamics of the external digital environment and technological risks. The emphasis is on the importance of designing flexible information potential management systems that are able to quickly respond to changes and minimize the negative impact of crises. However, the issues of ensuring the scalability of the proposed models for enterprises with different levels of digital maturity remain unresolved, and there are no formalized methods for quantitatively assessing the flexibility of management systems in the face of digital threats. The likely reason is a limited sample that does not take into account industry specificity and regional differences, as well as the use of a quasi-statistical approach, which complicates the accurate modeling of complex digital relationships in the energy sector.

In [8], the relationship between the level of digital culture and the effectiveness of the implementation of innovative technologies is analyzed. It is proven that the formed digital culture contributes to better adaptation of personnel to changes, increases motivation and the quality of information potential management. However, the issues of practical implementation of approaches to the formation of digital culture in the specificity of the energy industry have not been resolved, and the mechanisms of its influence on the structural elements of the enterprise's digital platform have not been sufficiently investigated. The likely reason is the focus of the study on general organizational aspects without taking into account industry differences, as well as the lack of a quantitative assessment of the effectiveness of digital culture as an element of the information potential management system.

Paper [9] examines the risks associated with cyber threats and proposes an approach to integrating protection mechanisms into a general model of digital transformation, which ensures comprehensive protection of information potential and the stability of the enterprise's operation. However, the issues of scalability of the proposed approach for enterprises of different sizes and levels of digital maturity, as well as the adaptation of cyber protection models to conditions of limited resources and flexible organizational structures, have not been resolved. The likely reason is limited empirical coverage, focus on large industrial companies with established organizational cultures, and insufficient attention to the specificity of less structured or small enterprises.

In [10], a methodology based on multi-criteria assessment of various aspects of digital transformation, including the technological level, organizational processes, and the human factor, is proposed. The importance of a systematic approach and regular monitoring of changes is emphasized. However, the issues of practical application of the proposed model under the conditions of heterogeneity of energy enterprises, as well as mechanisms for validating multi-criteria assessment in a dynamic digital environment, remain unresolved. The likely reason is the lack of empirical confirmation of theoretical provisions, limitations on practical verification in real organizations, and the difficulty of adapting the model to rapid technological changes in management structures.

In [11], a methodological model of prompts is described, designed to optimize interaction with modern language technologies. Five key principles of effective query formulation and their application in the digital environment are defined. However, the issues of assessing the effectiveness of the application of this model under production conditions, as well as the integration of language technologies into the general system of information potential management of the enterprise, remain unresolved. The likely reason is the lack of empirical analysis of the implementation results, limited testing in actual organizational environments, as well as insufficient adaptation of the model to the industry-specific nature of digital processes in the energy sector.

In [12], the authors analyze the impact of the digital infrastructure gap on the innovation gap between regions, taking into account the role of the industrial structure and the innovation ecosystem. A digital infrastructure index is constructed for a comprehensive assessment of regional differences. However, the issues of quantitative interpretation of the threshold effect of digital infrastructure and its impact on the dynamics of the development of the information potential of enterprises in the regional context remain unresolved. The likely reason is the lack of precise analytical criteria for determining the level of critical infrastructure, limited empirical data on the long-term impact of the digital divide, as well as the lack of research into adaptive mechanisms for regional digital alignment.

A generalization of the results from our review of the literature [1–12] allows us to identify a number of unresolved problems in the field of managing the information potential of energy enterprises in the context of digital transformation:

– the lack of an integrated model of digital coherence that would combine technical, strategic, cultural, analytical, and cybersecurity components into a single management system that enables the coherence of information potential;

– insufficient level of development of methodologies for assessing digital culture and its impact on the effectiveness of decision-making and the dynamics of transformation processes in the information environment of energy enterprises;

– no unified, holistic approach to formalizing a digital strategy as a basis for effective management of the information potential of an energy enterprise in connection with digital platforms, data architecture, and management processes;

– limited quantitative digital tools that do not allow for a full measurement of the effectiveness of implementing the information potential of energy enterprises;

– lack of criteria and indicators for comparative analysis, which does not allow for a comparative assessment of the level of development of information potential between different energy enterprises;

– low adaptability of models to the conditions of the digital environment, which does not make it possible to take into account the dynamic nature of external challenges (energy crises, cyberattacks) and ensure the necessary level of flexibility and resiliency of the digital infrastructure;

– the lack of integration of the cybersecurity component, which limits the potential for forming the digital resilience of energy enterprises in the face of growing cyber threats;

– ignoring analytical potential as a critical element, which does not make it possible to process and interpret large data sets to support decision-making regarding the management of the information potential of enterprises.

This list of unresolved issues represents a sound basis for further development of a consolidated model of digital coherence in the management of the information potential of energy enterprises, which would take into account modern challenges and the need for adaptive management of information resources.

3. The aim and objectives of the study

The purpose of our study is to build a consolidated model of digital coherence, which enables systematic, coordinated, and adaptive management of the information potential of energy enterprises in the context of digital transformation. The expected practical results of the implementation of the consolidated model of digital coherence are:

– reduction of operating costs and acceleration of management processes by eliminating digital gaps, automating and optimizing information flows;

– increasing the productivity of management personnel and the quality of decision-making through the implementation of coordinated analytical digital tools and formalized digital data;

– reduction of response time to external changes and increased adaptability of information potential management through the integration of strategic, technological, and analytical levels;

– reduction of information risks and ensuring cyber resilience by creating a secure information potential management environment.

To achieve the goal, the following tasks were set:

– to improve the categorization of existing digital transformation models for managing the information potential of energy enterprises;

– to form a system of criteria and indicators for assessing the digital coherence of energy enterprises, in particular in strategic, technological, cultural, analytical, and cybersecurity dimensions;

– to test the proposed model on the example of an energy enterprise (ZTPP) taking into account the retrospective dynamics of changes in the integrated digital coherence index (2012–2024) and crisis impacts (in particular, the war period).

4. The study materials and methods

The object of our study is the process of managing the information potential of energy enterprises under the conditions of digital coherence.

The hypothesis of the study assumes that the construction of a consolidated model of digital coherence in managing the information potential of energy enterprises could enable a higher level of coherence of strategic, technological, organizational, cultural, and analytical components, which, in turn, would contribute to:

– increasing the efficiency of digital transformation;

– improving adaptability to external risks (war, energy instability, cyberattacks);

– strengthening the innovative potential and digital resilience of the enterprise;

– optimizing data-based management processes.

Before starting the study, the following scientific assumptions were adopted:

– the information potential of the enterprise is an integrated system that includes resources, competencies, data, IT infrastructure, analytical tools, and digital culture;

– digital coherence is a measurable phenomenon that can be formalized through indices, criteria, and an integrated model;

– the level of digital coherence directly affects the effectiveness of management decisions and the ability to adapt;

– energy enterprises operating in different regions have common structural features, which allows for comparative assessment.

The following simplifications were adopted in the research process:

– the specific features of individual energy sub-sectors are not taken into account (differences between thermal and hydroelectric power plants);

– the constancy of digital parameters within one measurement period (year, quarter) is assumed, even if in fact they may change;

– cyber risks are assessed through aggregated indicators, without detailing at the level of individual incidents;

– the model assumes the rationality of management decisions, i.e., the absence of intentional distortions or sabotage;

– analytical data is aggregated to the level of the energy enterprise, without taking into account the local specificity of individual production units.

Thus, a coordinated digital consolidated model makes it possible to transform information potential into a strategic resource that forms the basis for the sustainable development of energy enterprises in the modern digital environment.

To build a consolidated model of digital coherence in managing the information potential of energy enterprises, a set of research methods was used, which include theoretical analysis, a systems approach, modeling, and empirical verification.

1. Theoretical and methodological methods:

– for systematizing existing concepts of digital transformation, digital coherence, information potential management;

– for generalization and synthesis to form a theoretical basis and build a logical-semantic structure of the model;

– for critical analysis to identify gaps, unresolved problems, and contradictions in scientific approaches.

2. Methods of systemic and structural-functional analysis:

– for building a structure of a digital coherence model, which harmonizes strategic, organizational, technological, and analytical elements of information potential management;

– for identifying relationships between components of information potential (technology, digital culture, cybersecurity, analytics, etc.).

3. Modeling methods:

– for conceptual modeling to build a consolidated model of digital coherence;

– for factor modeling to select and group the criteria for assessing coherence;

– for indexing to calculate the integrated index of digital coherence based on selected indicators.

4. Data visualization methods:

– for constructing graphs, histograms, and relationship diagrams;

– for visual representation of the model structure and changes in digital coherence indicators.

5. Expert evaluation methods. To determine the weight coefficients of the criteria and indicators that form the digital coherence index, the following expert evaluation methods are used:

Pairwise comparison method for the strategic level (indices, groups of indicators), the essence of which is that experts compare each pair of criteria in terms of importance according to the pairwise comparison matrix.

Methods for checking the consistency of assessments – to check for consistency, the consistency index (In_{YZ}), the consistency criterion (K_{YZ}), the Kendall concordance coefficient (K_{KK}), and the criterion for statistical verification of consistency (χ^2) are calculated.

The consistency index (In_{YZ}) is an analytical indicator (1) used to assess the level of consistency (coherence) between individual components of a complex system, in particular the information potential of energy enterprises in the digital environment

$$In_{YZ} = 1 - \frac{Qv_{Sk}}{Sr_{Sa}}, \tag{1}$$

where In_{YZ} is the coherence index; Qv_{Sk} is the standard deviation in the values of key parameters (e.g., digital transformation, information activity, cyber security, etc.); Sr_{Sa} is the arithmetic mean of the same parameters.

The coherence coefficient (K_{YZ}) is an indicator (2) used to assess the degree of internal coherence (coherence) between elements (indicators) of a complex system, for example, between digital subsystems of an energy enterprise. Unlike index In_{YZ}, this coefficient usually expresses the normalized level of balance, i.e., the relative deviation from the ideal state

$$K_{YZ} = 1 - \frac{1}{n} \cdot \sum_{i=1}^{n} \left| \frac{x_i - x}{x} \right|, \tag{2}$$

where x_i is the value of the i-th indicator (system component); x is the arithmetic mean of all x_i; n is the number of indicators.

The Kendall concordance coefficient (K_{KK}) is a rank-order statistical indicator (3) used to assess the degree of agreement between several experts or internal consistency between different variables (indicators)

$$K_{KK} = \frac{12 \cdot \sum Qk_v}{m^2 \cdot \left(n^3 - n\right)}, \quad (3)$$

where K_{KK} is the Kendall concordance coefficient; m is the number of experts (or sources/methods/groups of indicators); n is the number of objects (e.g., indicators, enterprises, or time periods); $\sum Qk_v$ is the sum of the squares of deviations in the ranks for each object from the average rank.

The criterion for checking significance (χ^2) is the indicator (4) for confirming the statistical reliability of the distribution of weights (W_i)

$$\chi^2 = m \cdot (n-1) \cdot K_{KK}, \quad (4)$$

where χ^2 is the criterion for statistical consistency testing ($\chi^2 > \chi^2_{krz}$, where critical value χ^2_{krz} is found from the chi-square distribution table); m is the number of experts (or evaluators/modules); n is the number of objects (indicators); K_{KK} is the Kendall concordance coefficient.

Our study is based on a combination of managerial, informational, economic-mathematical, and technological approaches, which makes it possible not only to build a model but also verify its effectiveness under the conditions of an actual enterprise.

5. Results of constructing a consolidated model of digital coherence in the management of the information potential of energy enterprises

5. 1. Improving the categorization of existing digital transformation models for managing the information potential of energy enterprises

Digital transformation is a key process for energy enterprises that seek not only to adapt to the changing technological environment but also to actively use the latest technologies to achieve strategic and operational goals. Among the main models of digital transformation, several approaches can be distinguished, each of which has its own advantages and disadvantages.

Analysis of these models allows us to assess which of them are best suited for certain types of businesses, depending on their size, industry, technological development, and strategic goals. The study is aimed at identifying effective approaches to ensuring digital coherence in the information environment, which allows energy enterprises to successfully adapt to the constantly changing technological process.

An analysis of existing models of digital transformation at enterprises was conducted, which revealed that the digital coherence model focuses on the integration of digital technologies into the management of the information potential of an energy enterprise.

The basic tasks and functions of digital models are given in Table 1.

The digital strategy model focuses on integrating digital technologies into the strategic management of an energy enterprise. Within the framework of this model, digital technologies are not considered as a separate tool or process, but as an important part of the overall strategy of an energy enterprise. The digital strategy covers all aspects of business and energy production: from improving productivity to creating new digital models.

Table 1

Basic tasks and functions of digital transformation models in managing the information potential of energy enterprises

Model	Tasks	Functions
Digital strategy model	Creating new digital technologies for strategic management of information potential of enterprises	Integration of digital technologies into the production processes of energy enterprises, marketing, and customer service
Model of digital platforms	Creating digital platforms that combine various technological processes into one integrated digital system	Ensuring convenient interaction of digital platforms with suppliers, partners and customers through a single interface point of the digital environment, uniting large masses of users on one digital platform
Model of innovative technologies	Applying innovative technologies to transform energy production and service into innovative ones, introducing automation, robotics, and self-management technologies into the energy industry	Implementation of advanced innovative technologies, such as artificial intelligence, the Internet of Things, big data, robotics, and automation, to improve or create new products, services, and business models
A model of digital culture	Building a corporate culture that supports digital transformation through the active involvement of employees in the use of new technologies, innovations, and changes in the organizational processes of the energy enterprise	Implementation of digital literacy among all employees and creation of conditions for their training and adaptation to new technological conditions of energy production, by actively investing in the development of digital culture at all levels of the energy enterprise, in particular through training programs and support for innovation

Advantages of the digital strategy model [13]:

– a strategic approach makes it possible to clearly define how digital technologies can support overall business goals;

– it allows the businesses to actively respond to technological changes, adapting their strategy to new opportunities and threats;

– it simplifies the integration of technologies into all business processes.

Disadvantages of the digital strategy model:

– it requires significant investments in research and development, as well as in attracting specialized personnel;

– it might prove difficult to apply at small and medium-sized enterprises that do not have a sufficient budget for a comprehensive digital transformation.

The digital platform model focuses on creating digital platforms that combine various business processes into a single integrated system. Digital platforms provide convenient interaction with suppliers, partners, and customers through a single interface point. It can include e-commerce platforms, big data analytics platforms, supply chain management systems, etc.

Advantages of the digital platform model [14]:

– it makes it possible to collect various aspects of the business into a single system, ensuring more effective interaction and speed of operations;

– it provides scalability and flexibility, which is especially important for fast-growing companies;

– it helps reduce costs by automating processes and improving management decisions through the analysis of big data.

Disadvantages of the digital platform model:

– high complexity in the development and integration of such platforms;

– it requires significant financial and technological resources at the launch stage;

– platforms can be too complex for small businesses that do not have experience working with such technologies.

The innovative technology model is a conceptual framework that describes the process of devising, implementing, and developing innovative technologies in the field of energy enterprises. Such a model makes it possible to systematize innovation processes, assess their effectiveness, and predict results.

Advantages of the innovative technology model [15]:

– it provides direct productivity improvement through the use of innovative solutions;

– it allows for significant cost reductions, especially in areas requiring high automation;

– it supports the development of new business models and allows for the creation of unique offers for consumers.

Disadvantages of the innovative technology model:

– innovative technologies often require significant investments, as well as time to integrate them into existing systems;

– high level of risk due to uncertainty of results and the need for constant updating of technologies.

The digital culture model focuses on building a corporate culture that supports digital transformation through the active involvement of employees in the use of new technologies, innovations, and changes in organizational processes. An important aspect is the development of digital literacy among all employees and the creation of conditions for their training and adaptation to new technological conditions [14].

Advantages of the digital culture model [16]:

– it helps prepare the organization for digital changes and enable long-term support for transformations;

– it promotes the development of an innovative culture, which is necessary for continuous improvement;

– it reduces resistance to change from employees since they are all involved in the change process.

Disadvantages of the digital culture model:

– it requires long-term efforts and time to form and implement such a culture;

– the model may be difficult to implement in companies with an established corporate culture or in those where the staff has limited experience with digital technologies.

The results of our analysis of theoretical approaches and practical implementation of existing models of digital transformation – in particular, models of digital strategy, digital platforms, innovative technologies, digital culture – indicate a partial role in the management of IP. The separate application of each model may be effective in a narrow functional context but does not enable a holistic digital transition of the enterprise.

To put it into context:

– the digital strategy model allows for the formulation of visions and vectors of digital transformation, but has limited practical implementation without a technological base;

– the digital platform model enables the integration of data and processes, but without an appropriate culture of using platforms and proper personnel competence – the effectiveness is low;

– the innovative technology model creates technical opportunities for improvement, but does not guarantee changes in management approaches;

– the digital culture model contributes to the transformation of personnel thinking but requires support from technologies and processes.

Thus, none of the models is universal but their synthesis makes it possible to achieve digital coherence, that is, consistency between the strategic, technological, process, and human components of IP management. Therefore, there is an objective need to devise a single model of digital coherence, which:

– combines strategic management, digital platforms, innovative technologies, and organizational and cultural changes;

– provides for a dynamic balance between technical innovations and the adaptability of the management system;

– makes it possible to form an integrated infrastructure for managing the information potential of an energy enterprise, capable of quickly adapting to the challenges of the energy market, cyber threats, and crisis events.

In addition, under conditions of high instability and increased risks (martial law, energy security, disruptions in supply chains), a single coherent digital model provides energy enterprises with a systemic adaptation tool. This makes it possible to maintain functioning, make informed decisions, and maintain competitive advantages.

It is proposed to consider four integrated subsystems (Table 2) as the basis of a single digital model, each of which performs a separate task in forming the information potential management system of energy enterprises.

Table 2

Integrated subsystems of a single consolidated model of digital coherence in managing the information potential of energy enterprises

Subsystem	Tasks	Main functions
Digital strategy	Forms a vector for the transformation of information potential	Integration of digital solutions into strategic management, marketing, service, production
Digital platforms	Ensures digital integration	Connecting business processes, suppliers, customers through a single digital infrastructure
Innovative technologies	Creates a technological base for information potential	Implementation of automation systems (SCADA); Internet of Things (IoT); artificial intelligence (AI); big data (Big Data); automation; smart systems (smart systems)
Digital culture	Promotes internal adaptation	Creating a digitally oriented environment through education, innovation support, competence development

The main tasks of the subsystems of the unified digital model:

– ensuring the unity of the digital infrastructure, covering all levels of management – strategic, operational, analytical;

– creating conditions for flexible management of the information potential of an energy enterprise in an unstable external environment (technological, military, market crises);

– forming indicators of digital coherence (coherence index, level of digital culture, degree of automation);

– increasing organizational adaptability through innovative approaches to managing data, knowledge, systems, and people.

The following basic digital technologies that could be used in a unified model of digital coherence in the context of the digital transformation of energy enterprises have been considered:

1. Digital technology "Internet of Things" (IoT) – this is a concept according to which physical devices (sensors, meters, devices, network equipment) are connected to the Internet and transmit data in real time. In energy enterprises, IoT is used for monitoring the state of technological equipment; network load management; energy consumption control; accident and breakdown prediction.

2. Digital technology Artificial Intelligence (AI) is a set of technologies that allow machines to analyze large amounts of data, learn from patterns, and make decisions. In energy companies, digital AI technology is used to optimize energy consumption; forecast demand; automatically manage energy generation and distribution; detect anomalies in data related to cybersecurity.

3. Digital technology "Big Data" are technologies and methods for collecting, storing, processing, and analyzing very large amounts of data from various sources (control systems, sensors, SCADA ACS, etc.). In energy enterprises, digital technology "Big Data" is used to build real-time analytics; identify trends, risks, and threats; justify strategic decisions; increase transparency in managing the information potential of energy enterprises.

4. Digital technology "Automation" is the implementation of automated control systems (ACS), which make it possible to implement production, dispatch, or function analytically without direct human participation. In the context of energy, automation includes automatic regulation of power system modes; remote control of technological equipment; unmanned production processes; automatic reporting and energy quality control.

5. Digital technology "Smart Systems" are intelligent solutions that combine digital tools IoT, AI, Big Data, and automation into a single managed ecosystem. Energy enterprises use a smart energy network that independently balances the load; a digital twin of the enterprise or power unit; a system for preventive maintenance of technological equipment of the power unit of power plants. Thus, all these components of digital technologies together form the technical basis of the information potential of a modern energy enterprise, ensuring efficiency, flexibility, and security of management under conditions of digital coherence.

5. 2. Devising a system of criteria and indicators for assessing the digital coherence of energy enterprises

The choice of criteria and indicators for a single digital model of digital coherence in managing the information potential of energy enterprises has been justified (Table 3).

To measure digital coherence indicators, as the level of consistency between information resources, digital technologies, management decisions, and human capital, the system of indicators should be based on technologies and models of digital strategy, platform, culture.

The assessment is carried out according to a system of criteria and corresponding indicators that make it possible to quantitatively measure the degree of integration of digital solutions in managing the information potential of energy enterprises.

The following criteria for the model of digital coherence in managing the information potential of energy enterprises are proposed:

– strategic coherence: the consistency of the digital strategy with the information potential and business goals;

– technological coherence: the level of integration of digital technologies into operational activities;

– platform coherence: the degree of integration of digital platforms and interaction with partners;

– innovation coherence: the ability to implement innovations and adapt;

– cultural and organizational coherence: the readiness of personnel for digital transformation;

– analytical coherence: the ability to use data to manage the information potential of energy enterprises;

– cybersecurity: the security and sustainability of the digital ecosystem.

These criteria of the digital coherence model perform an important function of assessing, monitoring, and managing digital transformation in enterprises. They make it possible to structure digital transformation.

Each criterion is responsible for a separate dimension of digital coherence:

– strategic coherence ensures that digital transformation does not occur spontaneously but corresponds to the mission, business goals, and potential of the enterprise;

– technological coherence enables the seamless integration of IT solutions into production and operational processes.

With the help of these criteria, one can assess how ready the enterprise is to implement new technologies; where there are weaknesses (low analytical coherence); which aspects require priority intervention. Digital coherence is not just the implementation of digital solutions but their consistency with each other and with the entire management system. Therefore, these criteria make it possible to avoid digital fragmentation, achieve synergy between strategy, technologies, platforms, personnel, and analytics. In addition, based on these criteria, it is possible to build a digital coherence index, which provides a quantitative assessment of the level of development of the enterprise in the digital environment. Since the information potential covers data, IT infrastructure, personnel, and management decisions, these criteria help effectively allocate digital resources; make informed decisions based on analytics; protect the digital ecosystem of the enterprise. The following indicators of the digital coherence model for ensuring the management of IP of energy enterprises are proposed (Table 3).

The calculation of the integrated index of digital coherence for managing the information potential of an energy enterprise requires a multifactorial approach that covers the degree of development, integration, and consistency of digital components. To form an integrated index of digital coherence, it is necessary to use expert assessment methods to determine the weight coefficients of the criteria and indicators of digital coherence: $W_{DC} = 0.20$; $W_{CC} = 0.15$; $W_{EE} = 0.15$; $W_{PI} = 0.10$; $W_{IT} = 0.10$; $W_{CY} = 0.10$; $W_{CE} = 0.20$. To determine the weight coefficients of the criteria of digital coherence, a combined approach was used: the method of pairwise comparison for the strategic level (indices, groups of indicators); Kendall's concordance and the criterion of statistical verification of consistency. The study was conducted by 12 experts, including leading specialists in the fields of digital transformation, digital management, energy, information technology, and strategic management. The average experience of the experts in the relevant areas was over 10 years.

Table 3

Criteria and indicators of a single digital coherence model for managing the information potential of energy enterprises

Criterion	Indicator	Index calculation formula	Parameter
1. Analytical coherence	Level of digitalization of processes	$DC = \frac{N_z}{N_\Sigma}$ (5)	N_z – number of digitalized processes; N_Σ – total number of processes
2. Cultural coherence	Level of digital competence of personnel	$CC = \frac{Pr_{nav}}{P_\Sigma}$ (6)	Pr_{nav} – the number of employees who have undergone digital training; P_Σ – total number of staff
3. Innovative coherence	Coefficient of economic effect of digitalization	$EE = \frac{D_z}{V_z}$ (7)	D_z – additional income from digital solutions; V_z – digital transformation costs
4. Strategic coherence	Increase in productivity	$PI = \frac{E_p - E_d}{E_d}$ (8)	E_p, E_d – production volume before and after digitalization
5. Platform coherence	Operationality of digital implementations	$IT = \frac{T_{\max} - T_{vp}}{T_{\max} - T_{\min}}$ (9)	T_{vp} – actual implementation time; $T_{\max}$, $T_{\min}$ – scale limits
6. Cyber security	Cyber resilience	$CY = \frac{1}{1 - A_{cib}}$ (10)	A_{cib} – number of cyberattacks per period
7. Technological coherence	Environmental effect of digitalization	$CE = \frac{CO_{2D} - CO_{2P}}{CO_{2D}}$ (11)	CO_{2D} to CO_{2P} – volume of CO_2 emissions before and after digitalization

A statistical substantiation of the reliability of expert assessment was carried out. The consistency and reliability of expert assessments were checked using classical statistical indicators. To assess the internal consistency of the pairwise comparison matrix, the consistency index (1) was calculated, which was $In_{YZ} = 0.067$, as well as the consistency coefficient (2), which is $K_{YZ} = 0.051$ at a normative level of 0.1. This indicates acceptable accuracy and correspondence of judgments. To determine the overall degree of consistency of the rankings of criteria by experts, the Kendall concordance coefficient (3) was used, which is $K_{KK} = 0.79$ at a normative level of $K_{KK} > 0.7$. The calculated criterion for statistical verification of consistency (4) is $\chi^2 = 56.88$ at a normative level of $\chi^2 > \chi^2_{krz}$. This level indicates high consistency of judgments. Statistical indicators that confirm the reliability of the resulting weight coefficients are summarized in Table 4.

Thus, the established weighting coefficients of digital coherence criteria are statistically justified and can be used in further modeling and assessment of the level of digital maturity of energy enterprises. The aggregated weighting coefficients of digital coherence criteria were normalized and used further to calculate the integrated digital coherence index (In_{zk}) according to the following formula (12)

$$In_{zk} = W_{DC} \cdot DC + W_{CC} \cdot CC + W_{EE} \cdot EE_n + W_{PI} \cdot PI_n + \\ + W_{IT} \cdot IT + W_{CY} \cdot CY_n + W_{CE} \cdot CE, \quad (12)$$

where In_{zk} is the integrated index of digital coherence level assessment; W_{DC}; W_{CC}; W_{EE}; W_{PI}; W_{IT}; W_{CY}; W_{CE} – weighting factors of digital coherence indicators; CC – digital culture of personnel; EE – economic effect; PI – productivity; IT – efficiency; CY – cyber resilience; CE – environmental effect.

The integrated index of digital coherence level assessment is normalized within [0;1], as indicated in Table 5.

Table 5 makes it possible to determine the stage of digital development of the enterprise, identify weak components (low cyber resilience), and plan strategic measures to increase the integrated digital coherence index.

Table 4

Statistical indicators

Indicator	Indicator value	Acceptance criterion	Assessment
Consistency index (In_{YZ})	$In_{YZ} = 0.067$	$In_{YZ} < 0.1$	Consistency is acceptable
Coefficient of consistency (K_{YZ})	$K_{YZ} = 0.051$	$K_{YZ} < 0.1$	Consistency is acceptable
Kendall's concordance coefficient (K_{KK})	$K_{KK} = 0.79$	$K_{KK} > 0.7$	High consistency
Statistical significance(χ^2)	$\chi^2 = 56.881$	$\chi^2 > \chi^2_{krz}$ (55.758)	The agreement is statistically significant

Table 5

The value of the integrated index for assessing the level of digital coherence

Integrated index (In_{zk})	Coherence level	Characteristics of the level of digital coherence
0–0.3	Low	Digital fragmentation, degradation
0.3–0.6	Medium	Partial coherence
0.6–0.8	High	Coherence of most components
0.8–1.0	Full	Digital synergy (high level of digital interaction and coherence); strategic integrity

5. 3. Testing the proposed model on the example of Zaporizhzhia Power Plant over 2012–2024

Based on formulas (5) to (12), which are given in Table 3, calculations of key indicators of a single model of digital coherence of information potential management of an energy enterprise were carried out, with realistic input initial data on ZTPP:

– total number of business processes of the enterprise: 100;

– number of processes with digital systems (ACS SCADA, etc.): 68;

– number of employees: 500; those who have undergone digital training: 280;

– costs for digital transformation: USD 1,200,000;

– additional income due to digital solutions: USD 1,650,000;

– productivity (generated energy in GWh): before implementation – 870, after implementation – 950;

– time to implement a new IT system – 4 months;

– number of cyberattacks in 2023 – 3;

– CO_2 emissions before digitalization: 200,000 t/year, after digitalization – 180,000 t/year.

The results of the full calculation of the indicators of digital coherence components were carried out based on the provided initial data on ZTPP. Changes in the indicators of the ZTPP digital coherence model over the period 2012–2024 are considered, which are given in Table 6.

An analysis of the level of digital coherence in managing the information potential of an energy enterprise (ZTPP, 2012–2024) was conducted based on Table 6 and the histogram in Fig. 1. The results of calculations of key indicators and the integrated index of the unified model of digital coherence (In_{zk}) indicate uneven dynamics of digital transformation of information potential at Zaporizhzhia TPP over the period from 2012 to 2024. The analysis is based on 7 main component indicators: *DC* (digitalization of processes), *CC* (digital culture of personnel), *EE* (economic effect), *PI* (productivity), *IT* (operationality), *CY* (cyber resilience), and *CE* (environmental effect).

Key stages in the development of the level of digital coherence at ZTPP include:

– 2012–2013: the period of initial digitalization, when the integrated digital coherence index was 0.137 and 0.161, respectively. This stage reflects isolated IT initiatives, low level of digital competence of personnel, and limited implementation of automated systems;

– 2014–2015: the crisis of digital development, which manifested itself in a drop in the integrated digital coherence index to 0.125 and 0.116. The reasons were political instability, military conflict, reduced investment and freezing of digital initiatives, which led to a decrease in the pace of modernization and degradation of the digital infrastructure;

– 2016–2021: the phase of active digital integration. The integrated digital coherence index increased from 0.207 to 0.386. During that period, an enterprise resource planning system and SCADA ACS were implemented, personnel training was intensified, productivity increased, and the company switched to cloud platforms. There was an average level of digital coherence, which reached its peak in 2021;

– 2022–2023: digital degradation caused by a full-scale war, physical damage to IT infrastructure, and the growth of cyber threats. The integrated digital coherence index decreased to 0.261 in 2022 and to 0.228 in 2023. The stability of digital channels was disrupted, and environmental and economic efficiency decreased;

– 2024: the beginning of digital recovery (In_{zk} = 0.260). There is an increase in digital participation of employees, attempts to modernize information systems, although a full recovery to the 2021 level has not yet been achieved.

Thus, the integrated digital coherence index (In_{zk}) at ZTPP increased almost threefold in 2012–2021 (from 0.137 to 0.386), which indicates a successful increase in information potential. After 2022, there was a sharp drop in the level of coherence associated with military events, which requires urgent measures for cyber protection, restoration of cloud infrastructure, and improvement of digital skills of personnel. In 2024, a trend towards digital reintegration was observed, which could enable the restoration of information manageability and support for sustainable development under conditions of stabilization of the external environment. It is also necessary to note that 2022–2024 became a period of sharp digital rollback for ZTPP, caused by the crisis conditions of the war.

Table 6

Results of calculating the key indicators and the integrated index of a single model of digital coherence of information potential management of an energy enterprise

Year	Digital coherence indicators							Integrated index
	DC	*CC*	*EE*	*PI*	*IT*	*CY*	*CE*	In_{zk}
2012	0.18	0.12	0.20	0.08	0.15	0.20	0.10	0.137
2013	0.23	0.18	0.24	0.10	0.18	0.22	0.12	0.161
2014	0.17	0.14	0.16	0.05	0.12	0.18	0.08	0.125
2015	0.16	0.12	0.15	0.04	0.10	0.16	0.07	0.116
2016	0.28	0.25	0.35	0.10	0.25	0.30	0.15	0.207
2017	0.36	0.30	0.44	0.15	0.28	0.32	0.18	0.248
2018	0.44	0.38	0.52	0.20	0.33	0.34	0.20	0.289
2019	0.51	0.44	0.60	0.24	0.38	0.36	0.22	0.326
2020	0.58	0.50	0.66	0.28	0.42	0.38	0.25	0.360
2021	0.63	0.56	0.70	0.30	0.45	0.40	0.28	0.386
2022	0.43	0.35	0.48	0.12	0.20	0.25	0.12	0.261
2023	0.38	0.28	0.42	0.08	0.18	0.20	0.10	0.228
2024	0.45	0.33	0.50	0.11	0.22	0.23	0.14	0.260

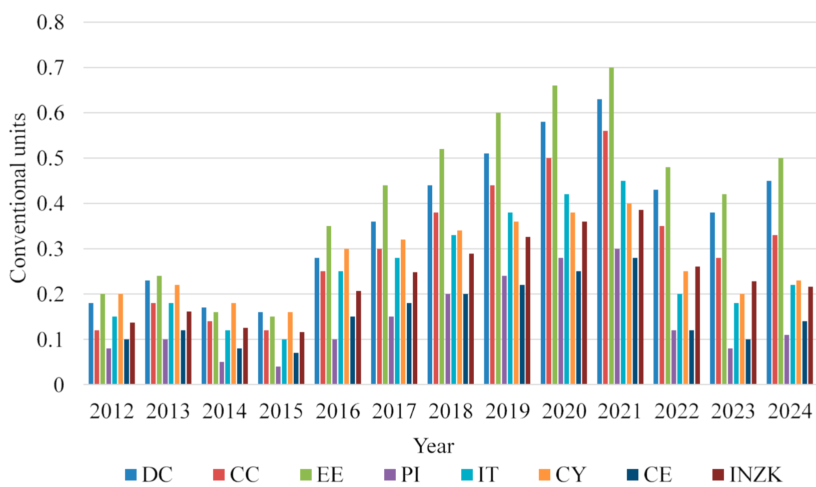

Fig. 1. Histogram of change dynamics in the main indicators and the integrated digital coherence index for Zaporizhia Power Plant over the period 2012–2024

The digital model of managing the information potential of the power enterprise needs to be re-launched, with a focus on restoring investments, personnel training, and environmental efficiency.

To improve the level of digital coherence at ZTPP, it is necessary to:

– increase investments in cyber resilience and restoration of the ZTPP power unit's ACS (SCADA systems;

– to continue digital training of personnel to increase digital culture;

– to use the results of calculating the integrated digital coherence index to monitor the ZTPP's digital maturity in real time;

– to integrate the digital coherence index into the strategic management of the ZTPP's information potential.

6. Discussion of results based on building a consolidated model of digital coherence in managing the information potential of energy enterprises

The categorization of digital transformation models has been improved through their critical analysis, structuring, and adaptation to the needs of energy enterprises. In contrast to existing approaches [17, 18], in which information components are ignored, it is proposed to consider information potential as a complex system that includes information, technical, organizational, and human resources. Our study has systematized four main models of digital transformation – strategic, technological, infrastructural, and behavioral-cultural. Comparative analysis (Table 1) revealed the limitations of their isolated application in managing information potential. This justifies the need to construct a consolidated model of digital coherence. The consolidated model assumes the coordinated functioning of four subsystems: digital strategy, platforms, technologies, and culture. Its structure (Table 2) takes into account strategic guidelines, infrastructure capabilities, technical innovations, and socio-cultural factors, ensuring coherence between all elements of digital development. The consolidated model helps overcome fragmentation, increase the manageability of transformation processes and the sustainability of information potential management of energy enterprises.

A system of criteria and indicators for assessing the digital coherence of energy enterprises has been designed, which provides a comprehensive reflection of the coherence between the strategic, technological, organizational, and socio-cultural aspects of digital transformation. The proposed criteria cover key components: strategy, IT infrastructure, human capital, analytics, cybersecurity, and innovative development. They perform diagnostic, monitoring and management functions, serving as a tool for systemic improvement of digital maturity. Table 3 gives a structured system of indicators, in particular the share of digitalized processes (analytical coherence), the share of employees with digital competencies (cultural coherence), the ratio of economic effect to digitalization costs (innovative coherence), etc. The use of quantitative indicators makes it possible to assess the current state, identify critical areas, and form a holistic picture of the level of digital coherence. To substantiate the integrated index of digital coherence (In_{zk}), an expert assessment of weighting coefficients was conducted (12 specialists with experience in digital management, energy, etc.). The consistency of the estimates was confirmed statistically (consistency index $In_{YZ} = 0.067$), which makes it possible to use the results in further modeling. The integrated index of the assessment of the level of digital coherence (In_{zk}), calculated from formula (12), determines the level of digital maturity of the enterprise within the interval [0;1] and is divided into four levels (Table 5). This provides the possibility of comparative analysis, strategic planning, and increasing the efficiency of managing the information potential of energy enterprises.

The digital coherence model was tested on the example of Zaporizhzhia TPP, which made it possible to empirically verify its applied significance and diagnostic ability. The calculation of the integrated index of the assessment of the level of digital coherence (In_{zk}) was carried out on the basis of formulas (5) to (12) and real data from 2012–2024 (Table 6), with further analysis of dynamics (Fig. 1). The phase unevenness of the digital transformation of the enterprise was established, caused by both internal managerial shifts and external destabilizing factors, in particular military events. The integrated index (In_{zk}) demonstrates the ability to reflect both the gradual increase in digital potential (growth from 0.137 to 0.386 in 2012–2021) and vulnerability to a systemic decline in 2022–2024. This confirms the sensitivity of the consolidated model to the level of digital coherence and its suitability for retrospective analysis and strategic planning. The identified dynamics (Fig. 1) emphasize the feasibility of using the model as a tool for anti-crisis management of information potential in the energy sector.

The model has several important limitations: it was tested only at one enterprise, so the conclusions cannot be automatically transferred to other organizations or industries. It is based on the assumption that all indicators are stable and their significance is the same, although in reality this is rarely the case. The data used were internal and partly subjective, and the influence of informal factors such as corporate culture, the level of digital literacy of employees or management style was not taken into account. The model requires adaptation to the specificity of each enterprise.

Among the main shortcomings are the lack of verification on other application examples, insufficient detailing of the methodology for assessing the economic efficiency of digital investments, a vague explanation of the reasons for the decrease in the index, as well as a weak analysis of the time dynamics of indicators.

Further research may focus on the connection between the information potential of the enterprise, its architecture, and economic potential. It is also necessary to conduct clustering of enterprises by the level of their information potential and analysis of the results. Research may involve comparative analysis of coherence indicators across enterprises, as well as modeling scenarios of the impact of digital innovations in the long term.

7. Conclusions

1. We have categorized existing digital transformation models used to manage the information potential of energy enterprises. The essence of the improvement is to formalize a new classification that includes models defined by the

level of coverage of information potential (partial, complex, systemic); by the type of orientation (technological, managerial); by the degree of coherence (isolated, integrated, coherent). The improved categorization has made it possible to identify the limitations of conventional models and justify the need to devise a consolidated model of digital coherence, which enables systemic consistency between digital resources, management processes, and digital culture. The result of improving the classification was the proposal of a more structured, systematic, and adapted to the needs of energy enterprises methodological framework, which formed the basis of a new model of digital coherence for managing information potential.

2. The devised system of criteria and indicators covers the key dimensions of digital coherence:

– strategic: it determines the ability of the enterprise to implement digital solutions within the framework of the overall business strategy;

– technological: it characterizes the degree of integration of digital platforms and automated processes;

– cultural: it reflects the level of digital literacy of the staff and the organization's openness to innovation;

– analytical: it shows the effectiveness of using data to make management decisions;

– cybersecurity: it enables resilience to digital threats and risks.

3. The model was tested on the example of Zaporizhzhia Thermal Power Plant, covering the period 2012–2024 and including an analysis of crisis impacts, in particular the period of military conflict. Our results showed a deterioration in the digital maturity of the enterprise, a decrease in the share of digitized business processes and the effectiveness of digital investments. The digital maturity of the power plant demonstrates regressive dynamics: the integrated digital coherence index decreased from 0.386 (2021) to 0.260 (2024), which indicates a degradation of the level of integration of digital solutions into the enterprise's management processes. Notwithstanding, our model reflects the ability to identify critical points of digital degradation, form adaptive scenarios of digital development, and provide an objective quantitative assessment through the integrated coherence index. All this confirms the practical suitability of the model for use under conditions of high turbulence in the digital environment.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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