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GEOINFORMATION SUPPORT FOR ENERGY RESOURCE PLANNING AND ACCOUNTING IN COMMUNITIES AS A TOOL FOR IMPROVING ENERGY EFFICIENCY AND ENSURING SUSTAINABLE DEVELOPMENT

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Анотація. *Стаття визначає методичні засади геоінформаційного супроводу планування та обліку енергетичних ресурсів на рівні територіальних громад. Запропоновано інтегрувати просторові масиви, цифрові реєстри комунальної інфраструктури, системи оперативного моніторингу та аналітичні інструменти управління. Окремо проаналізовано можливості геоінформаційних платформ під час інвентаризації об'єктів, фіксації втрат енергоресурсів та підготовки інвестиційних проєктів. Метою роботи є створення прикладної моделі застосування геоінформаційних технологій у процесі планування, моніторингу та обліку енергоресурсів на рівні громади. Увагу спрямовано на об'єднання відомостей про обсяги споживання, стан* *інженерних мереж, резерви локальної генерації та ймовірність аварійних ситуацій. Дослідження базується на чинних нормативних актах, офіційній статистиці, відкритих геопросторових матеріалах, технічних характеристиках мереж та реєстрах об'єктів комунального господарства. Методологічна частина включає системний аналіз, просторове моделювання, економічне пріоритезування заходів, сценарні розрахунки та порівняльну оцінку управлінських варіантів в сфері енергоспоживання. Автори аргументують необхідність формування єдиної цифрової бази енергетичних ресурсів територіальної громади. У статті представлено інструменти для візуалізації ділянок з надмірним споживанням, розрахунку технічних втрат у мережах та визначення майданчиків для розміщення сонячних, вітрових і біоенергетичних установок. Запропоновано метод відбору інвестиційних проєктів з урахуванням строку окупності, технічної доступності та впливу на довкілля. Доведено ефективність поєднання геоінформаційної системи з лічильниками віддаленого зчитування та місцевим геопорталом. Перспективним напрямом подальшої роботи вважається розробка цифрових двійників муніципальної інфраструктури. Доцільно також дослідити можливості штучного інтелекту у прогнозуванні енергетичних навантажень. Важливим завданням залишається створення галузевих стандартів для обміну просторовими даними.*

Ключові слова: *геоінформаційні системи, енергетичні ресурси, територіальна громада, енергоефективність, просторове планування, сталий розвиток.*

Introduction. The energy sustainability of communities increasingly depends on the quality of spatial data and the accuracy of technical accounting. Local heating, electricity, water treatment and outdoor lighting networks operate under challenging conditions, in which loads are unevenly distributed, and resource losses often remain unnoticed. Conventional reporting systems record finished outcomes but do not enable the precise spatial identification of problem areas. For this reason, geographic information technologies, digital maps and unified infrastructure registers are becoming highly practical tools. They help communities more accurately identify places of excessive costs, assess the possibilities of local generation and coordinate investment programmes. In many communities, geodetic monitoring, energy accounting, budget planning and emergency response still exist as separate management circuits. Such disunity reduces the effectiveness of investments, complicates the modernisation of networks and slows down the recovery of territories after crises. We assume that the combination of GIS platforms, smart-metering systems, spatial analytics, and digital risk maps can form a new model for managing community energy resources.

Analysis of recent researches and publications. In recent years, researchers have been paying more attention to digital management of energy resources at the level of individual territories. The work of A. Achkasov et al. [2] presents the results of a study of the geoportals of territorial communities and the features of their information content. The authors show that spatial services make management data more accessible. At the same time, the issues of integrating such platforms with energy accounting systems remain incompletely addressed. The study of I. Azhaman et al. [1] highlights the international experience of energy management and the possibilities of its adaptation in Ukraine. Resource consumption management, as the authors prove, gives a tangible economic effect. However, the mechanisms that enable management decisions to be developed in greater territorial detail, that is, at the level of an individual community, require further clarification.

In the publication by O.M. Sukhodolia [7], a model of risk-oriented provision of energy security of the state is proposed. The author convincingly demonstrates the importance of threat forecasting and resource reservation. However, the aspects of local risk mapping for specific network infrastructure facilities remained unresolved. The work of A. Buonomano et al. [8] presents the results of GIS-planning of energy communities in cities. Researchers show that spatial selection of generation, storage and demand balancing zones is effective. However, the extent to which such approaches can be adapted to Ukrainian communities with worn-out networks requires separate investigation. The study by A. Kochanek, A. Generowicz, T. Zacłona [12] reveals the role of geographic information systems in environmental management and the development of renewable energy. The authors rightly emphasise the interdisciplinary nature of GIS solutions. At the same time, the combination of environmental and budgetary criteria in municipal planning is not sufficiently covered.

In the scientific publication, W.G. Nassif, Y.K. Al-Timimi, D. Elhmaidi [16] substantiate the use of the GIS-AHP method for selecting sites for solar generation. The authors demonstrate the high accuracy of multi-criteria selection of territories. However, the question of how to jointly rank solar, bioenergy and cogeneration projects within a single community remains open. The work of M. Karpash et al. S. [11] is devoted to energy security plans of small municipalities of Ukraine. The researchers show the need for scenario planning and forecasting resource deficits. However, the topic of real-time digital monitoring is only partially covered. The study by S. Zaichenko, O. Borychenko, A. Trachuk [17] provides a geoinformation analysis of the development of renewable energy in Ukraine, considering the remoteness of consumers. The authors show that transport and network factors significantly affect the feasibility of project implementation. All this provides grounds for conducting a separate study on geoinformation support for energy resource management in communities.

Purpose. The purpose of the article is to develop applied methodological approaches for implementing geoinformation support in the processes of planning and accounting of energy resources at the community level.

Methods. The source base of the study comprises energy-sector regulatory documents, municipal development programmes, open geospatial data and statistical materials on resource consumption. This dataset includes cartographic layers of community territories, technical parameters of networks, data on budgetary institutions, as well as information on local energy generation. A systematic approach, comparative analysis and spatial modelling were used for analytical processing. Using GIS tools, it was possible to identify network overload zones, areas, as well as territories with increased risk.

Results. The transition of communities towards precise energy resource management directly depends on the quality of spatial data. This is because energy accounting has long evolved separately from the urban planning cadastre, while engineering infrastructure has often been described using local schemes developed by individual enterprises. A unified digital database of community energy resources should be based on the integration of several sources. This should include the state land cadastre, urban planning documentation, topographic plans, satellite images and GNSS survey results. Indicators of actual consumption of electricity, heat, water, and fuel are added to this system. The level of database completeness can be assessed using the spatial readiness coefficient:

$$K_{pg} = \frac{N_v}{N_z} \cdot 100\% \qquad (1)$$

where:

K_{pg} – coefficient of spatial readiness of the base, %;

N_v – number of verified objects;

N_z – total number of objects in the register.

If the value of the indicator exceeds 90%, the community already has a functioning digital model. If the value is lower, the system remains unstable, although it formally exists.

The next block concerns the geodetic positioning of energy consumption objects. This refers not only to school or hospital buildings. It is necessary to record boiler rooms, heat points, pumping stations, transformer substations, wells, lighting nodes, emergency sections of networks [16, p. 83]. Without accurate coordinates, maintenance becomes reactive (Figure 1).

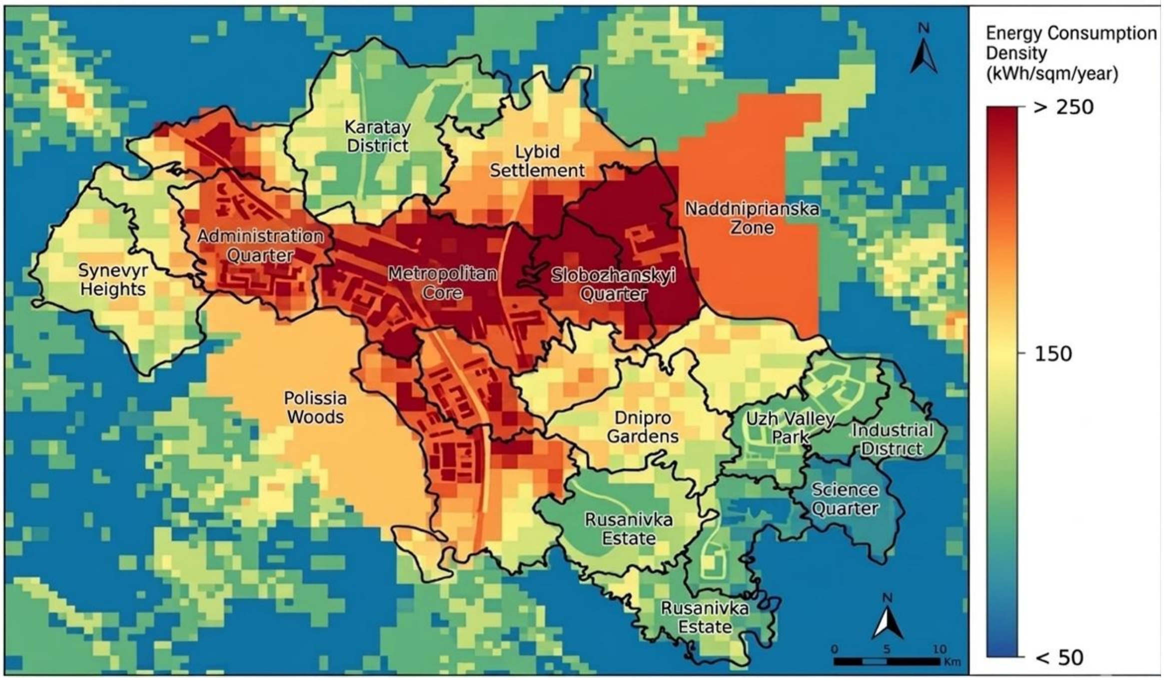

Figure 1. Spatial map of energy consumption density (kW/m²/year) in urban areas (constructed by the authors in SolidWorks)

It is advisable to determine the energy intensity of a spatial unit by the formula:

$$E_d = \frac{Q_{el} + Q_{th} + Q_f}{S} \tag{2}$$

where:

E_d – integrated energy intensity of the territory, kWh/m²;

Q_{el} – electricity consumption;

Q_{th} – thermal energy in reduced equivalent;

Q_f – fuel resources;

S – area of development or functional zone.

This indicator is effective for identifying neighbourhoods with abnormally high costs. Before proceeding to the registry, it is advisable to compare the structure of objects that are usually included in the digital database of the community (Table 1).

Table 1. Typical structure of a digital database of energy resources of a territorial community [3, 4]

No	Category of objects	Data source	Main metering parameter	Spatial format	Update Frequency	Digitalisation Priority
1	Educational institutions	Balance holder	kWh/year	Point/Polygon	Monthly	High
2	Medical institutions	Health department	Gcal/year	Polygon	Monthly	High
3	Administrative buildings	Community executive committee	kWh/m²	Polygon	Quarterly	Medium
4	Boiler rooms	Heating network management committee	Power, MW	Point	Quarterly	High
5	Street lighting	Land improvement management committee	Number of light points	Line/Point	Monthly	High
6	Substations	Network operator	kW	Point	Yearly	High
7	Water pumping stations	Water supply and sewerage	kWh/day	Line	Monthly	High
8	Heating networks	Heating network management committee	Loss, %	Spatial format	Yearly	High

The GIS registry of energy infrastructure should function as a decision-support system rather than as an archive. For each facility, the technical condition, year of introduction, wear, balance holder, energy consumption, photo fixation, repair history and replacement forecast are recorded. This enables the community to move from intuitive repair decisions to a managed investment cycle. The modernisation priority index should be defined as follows:

$$P_m = 0,45Z + 0,35L + 0,20C \tag{3}$$

where:

P_m – modernisation priority;

Z – wear level;

L – energy loss;

C – criticality of the facility for the population.

The higher the value of the indicator, the earlier the facility is included in the renewal programme. It is appropriate to demonstrate how the methodology works in practice using the example of the Kryvyi Rih urban territorial community. The territory of the community exceeds 430 km², and the city has an elongated building structure. This means long engineering corridors, a significant length of outdoor lighting, and high costs for dispatching. According to open data from the city council, dozens of utility companies operate in the community, a large network of educational and healthcare institutions, and the transport infrastructure includes tram and trolleybus systems. For such a territory, coordination costs inevitably increase in the absence of a GIS register. A practical case can be presented through a quarterly analysis model. If one district has 14 budget buildings with an average consumption of 182 kWh/m² per year, and a neighbouring district has 11 buildings with 126 kWh/m², the system immediately shows the loss zone. Insulation, heating units, lighting, and operating mode are checked [6, p. 128-129]. Table 2 provides an example of an analytical matrix that a community can use to develop an annual energy efficiency programme.

Table 2. Community energy facility modernization priority matrix [5, 14]

No	Object type	Wear, %	Energy loss, %	Priority index	Recommended action
1	Old school building	71	24	0,64	Thermal modernisation
2	Hospital building	66	21	0,58	Metering unit modernisation
3	Quarter boiler room	79	18	0,67	Equipment replacement
4	Pumping station	74	16	0,60	Frequency regulation
5	Street lighting	48	27	0,51	LED modernisation
6	Administrative building	53	14	0,43	Mode automation
7	Heating network section	81	29	0,74	Capital replacement
8	Sports complex	59	19	0,49	Local sanitation

Special attention is required for monitoring over time. A static map quickly becomes outdated. Therefore, the database should be combined with automatic import of meter readings, mobile surveys, and annual geodetic network revision. In this way, errors do not accumulate in the information system. The effect of digital management can be estimated using the savings formula:

$$K_e = \frac{C_0 - C_1}{C_0} \cdot 100\% \tag{4}$$

where:

K_e – cost savings, %;

C_0 – costs before GIS implementation;

C_1 – costs after implementation.

In municipal projects, a similar indicator is often formed due to fewer emergency repairs, loss reduction and more accurate budgeting. This appears to be the most valuable effect of the digital geodetic model of the community. When the map begins to function as a management tool, resources are no longer dispersed but concentrated in problem points. Therefore, geoinformation analysis is needed not as an addition to statistics, but as a separate system for detecting losses. When the map is combined with consumption indicators, hidden imbalances become visible. The first stage is to map areas of excessive energy consumption [2]. For this purpose, the territory of the community is divided into analytical cells, for example 250 × 250 m or 500 × 500 m. Then, the annual consumption of electricity, heat, natural gas, the number of residents, the built-up area and the length of the networks are linked to each cell [9, p. 4]. After this, an integral load index is formed.

$$I_{en} = \frac{\alpha Q_{el} + \beta Q_{th} + \gamma Q_g}{S^{0.65} \cdot P^{0.35}} \tag{5}$$

where:

I_{en} – energy load index of the territory;

Q_{el} – annual electricity consumption, kWh;

Qth – thermal energy, Gcal in reduced equivalent;

Q_g – gas consumption, m^3 in energy terms;

S – built-up area, m^2;

P – population;

α,β,γ – resource weighting factors.

Cells with an excess of the average value by 25–30% form a map of critical zones. The second task concerns losses in thermal and electrical networks. These losses are often dispersed across small areas, which is why traditional reporting tends to smooth out risks. Pipeline layers, cable routes, network age, failure rate, carrier temperature, line resistance are introduced into the GIS environment. A spatial loss coefficient is then formed.

$$K_{loss} = \sum_{i=1}^{n} \left(\frac{L_i \cdot Z_i \cdot \Delta T_i}{D_i} \right) + \sum_{j=1}^{m} \left(R_j I_j^2 t_j \right) \quad (6)$$

where:

K_{loss} – integral loss indicator;

L_i – length of the thermal section;

Z_i – wear coefficient;

ΔT_i – temperature difference;

D_i – pipeline diameter;

R_j – electrical resistance of the line;

I_j – current strength;

t_j – load time.

After the calculation, the system shows the areas where modernisation will give the greatest effect per unit of investment. Before further modelling, it is advisable to structure the technical parameters used in mapping energy consumption and network losses (Table 3) [12].

Table 3. Technical parameters of GIS analysis of areas of excessive energy consumption and network losses (developed by the authors)

No	Parameter	Unit of measurement	Data source	Spatial level	Update period
1	Electricity consumption	kWh/year	Accounting operators	Building	Monthly
2	Heat consumption	Gcal/year	Heat supplier	Building	Monthly
3	Heat network length	km	Technical passport	Quarter	Yearly
4	Network failure rate	cases/year	Utility company	Plot	Quarterly
5	Building density	m²/ha	Cadastre	Quarter	Yearly
6	Equipment age	years	Balance holder	Object	Yearly

No	Parameter	Unit of measurement	Data source	Spatial level	Update period
7	Transformer load	%	Energy company	Substation	Monthly
8	Voltage losses	%	Dispatch accounting	Line	Monthly

The next block is related to GIS-modelling of suitable areas for local generation. For solar stations, insolation, terrain slope, slope orientation, distance from substations, building restrictions and environmental regimes are used. For wind facilities, wind rose, surface roughness, sanitary zones and air navigation restrictions are added. Bioenergy, in fact, is oriented towards the logistics of raw materials, transport accessibility and distance to the heat consumer [17, p. 62]. It is advisable to determine the suitability of the site by the weighted overlay method:

$$S_{fit} = \sum_{k=1}^{r} w_k x_k - \sum_{h=1}^{q} p_h y_h \tag{7}$$

where:

S_{fit} – integral fitness score;

w_k – weight of positive criterion;

x_k – normalised value of positive factor;

p_h – weight of constraint;

y_h – normalised value of negative factor.

The plots with the highest score are included in the first round of investment consideration. However, high natural suitability does not always imply high economic feasibility. Therefore, after the technical selection, a financial filter is applied. For this purpose, a spatial payback index is calculated:

$$R_{pay} = \frac{CAPEX + \sum OPEX_t (1+r)^{-t}}{\sum CF_t (1+r)^{-t}} \tag{8}$$

where:

R_{pay} – payback index;

$CAPEX$ – initial capital expenditure;

$OPEX_t$ – operating expenses of year t;

CF_t – cash flow of year t;

r – discount rate.

If the index is less than one, the project has an acceptable financial profile. Before making a final investment choice, the community should compare technical feasibility with connectivity and environmental impact. At this stage, GIS becomes a strategic ranking tool (table 4).

Table 4. Technical prioritisation matrix for local community energy projects (developed by the authors)

No	Project type	Technical score, units	Distance to network, km	CO_2 reduction, t/year	Priority
1	Ground-site solar power plant 5 MW	8,9	0,8	4120	High
2	Rooftop solar power plant of a school	7,1	0,1	96	Medium
3	Local wind power plant 3 MW	8,4	1,6	3580	High
4	Bio-boiler plant 2 MW	7,8	0,4	2140	High
5	Gas-piston cogeneration	6,5	0,3	980	Medium
6	Battery module	7,3	0,2	0	Medium
7	Heat pumps for housing and communal services	7,9	0,2	620	High
8	Micro-solar power plant for water utility	6,9	0,1	74	Medium

The third stage concerns the spatial prioritisation of investment projects. At this stage, not a single indicator but a set of parameters is assessed: payback, number of consumers, capacity reserve, environmental effect, technical risk, land availability. If decisions are made without a map, conflicts are almost inevitable. When the decision is based on a spatial matrix, the management logic becomes more transparent [15, p. 492]. A comprehensive rating can be defined as follows:

$$Q_{inv} = 0.30F + 0.25A + 0.20E + 0.15T + 0.10R^{-1} \tag{9}$$

where:

Q_{inv} – integral project rating;

F – financial efficiency;

A – infrastructure availability;

E – environmental impact;

T – technical readiness;

R – implementation risk.

Data arrives with a delay, losses accumulate earlier, and repair decisions are made too late. For this reason, geodetic monitoring is now shifting towards continuous observation. The coordinates of the object, the time series of consumption, the technical condition of the equipment and spatial connections should function as a single system.

The integration of the GIS platform with smart metering begins with linking each metering node to the coordinate base of the community. A meter without a coordinate gives only a number [10]. A meter in a geographic information system provides the context: district, balance holder, type of development, power substation, emergency risks (Figure 2).

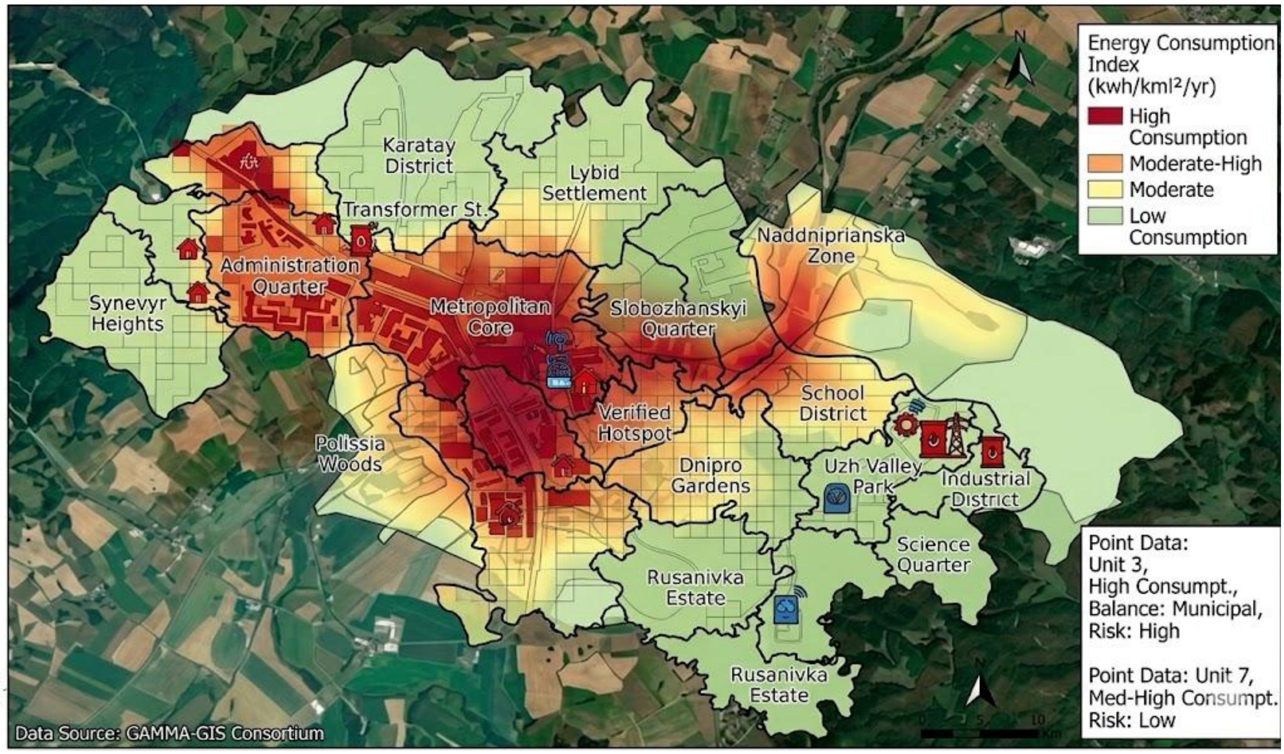

Figure 2. Heat map of energy consumption: GIS analysis of the city (built by the authors in SolidWorks)

For current control, an aggregated indicator of instantaneous load deviation is used:

$$D_t = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{q_{it} - \bar{q}_i}{\sigma_i}\right)^2} \quad (10)$$

where:

D_t – integral deviation at time t;

q_{it} – current consumption of object i;

q_i^{-} – average normative consumption;

σ_i – standard deviation of the series;

n – number of controlled nodes.

If the indicator exceeds the threshold value, the dispatcher immediately sees the sector of abnormal load. The real-time system should combine electricity, heat, water, gas meters, the state of pumping equipment and voltage parameters. Integration with GNSS sensors on mobile teams makes a special sense. This provides control over the response time, route of movement and the actual location of work.

Before deploying a digital dispatch circuit, it is advisable to fix a set of technical parameters that the community should collect automatically. Without this, the data flow quickly turns into noise (Table 5).

Table 5. Technical parameters for integrating GIS platforms with smart-metering systems (developed by the authors)

No	Monitoring parameter	Unit	Signal source	Refresh rate	Spatial level
1	Active power	kW	Electricity meter	15 minutes	Building
2	Thermal load	Gcal/h	Heating unit	15 minutes	Building
3	Network pressure	bar	Pressure sensor	5 minutes	Site
4	Phase voltage	V	Network analyser	1 minute	Substation
5	Water consumption	m^3/h	Water meter	15 minutes	Object
6	Media temperature	°C	Temperature sensor	5 minutes	Heating network
7	Brigade arrival time	minutes	GPS tracker	Event	District
8	Equipment status	0/1	PLC controller	Online	Object

The community geoportal acts as the next level of management. If the internal GIS system is focused on operators, then the geoportal works for management, financial departments and residents. It displays completed repairs, consumption of budget institutions, savings dynamics, status of investment projects, network loading

[13, p. 224]. However, without standardised visualisation, the manager sees an attractive map rather than a decision-making tool.

To assess the implementation of energy efficiency programmes, it is advisable to use the budget performance index:

$$B_{ef} = \frac{\sum_{j=1}^{m} \left(S_j \cdot \eta_j\right)}{\sum_{j=1}^{m} C_j} \tag{11}$$

where:

B_{ef} – budget effectiveness index;

S_j – annual savings for measure j;

η_j – target effect achievement coefficient;

C_j – budget expenditure for the measure;

m – number of projects.

The higher the indicator, the more accurately the budget is transformed into a real resource-saving result. In the geoportal, it is useful to display not only completed work, but also a forecast of cash needs by the end of the year. In this way, the finance department sees not merely the remaining funds, but also the future budget tension. This is why a digital map is increasingly becoming a treasury planning tool. A separate block concerns digital maps of energy security risks. This combines network failure rates, the degree of wear, power reserve, population density, critical facilities, and logistical availability of repair services [11]. In the event of an emergency, the community should know which area is most vulnerable and which area can temporarily take the load. The integral risk of the territory should be determined as follows:

$$R_z = \lambda_1 A + \lambda_2 Z + \lambda_3 P + \lambda_4 C - \lambda_5 R_s \tag{12}$$

where:

R_z – zone risk;

A – network failure rate;

Z – degree of deterioration;

P – consumer density;

C – criticality of social facilities;

R_s – network reserve capacity;

$\lambda_1 \ldots \lambda_5$ – weighting factors.

The areas with the maximum value are included in the first stage of modernisation and reservation. Before developing post-crisis recovery scenarios, it is advisable to structure the types of risks and the corresponding technical responses of the community (Table 6).

Table 6. Matrix of digital risk analysis and scenarios for energy infrastructure restoration (developed by the authors)

No	Risk type	Probability	System Impact	Response time	Action Priority
1	Substation damage	High	Loss of District Power	Up to 30 min	Critical
2	Heating network failure	High	Decreased Sector Temperature	Up to 1 h	High
3	Feeder overload	Medium	Emergency Shutdown	Up to 15 min	High
4	Pumping station failure	Medium	Water Outage	Up to 30 min	High
5	SCADA cyberattack	Low	Loss of Control	Immediate	Critical
6	Local fuel shortage	Medium	Generation Limitation	Up to 6 h	Medium
7	Sensor communication failure	Medium	Loss of Telemetry	Up to 2 h	Medium
8	Massive icing of networks	Low	Multiple Damage	Up to 12 h	High

Post-crisis recovery should be based not on the principle of priority of applications, but on a spatial rating of criticality. For this purpose, a recovery priority indicator is introduced:

$$V_p = \frac{N_c \cdot W_s \cdot T_r^{-1}}{C_r^{0.5}} \tag{13}$$

where:

V_p – priority of restoration;

N_c – number of consumers;

W_s – weight of social significance;

T_r – expected repair time;

C_r – resource cost of works.

The higher the index value, the earlier the facility is included in the disaster recovery schedule. The functioning of such a system is particularly evident during peak loads. GIS identifies the problem area, smart metering confirms the parameters, the geoportal opens the budget resource, and the repair service receives the route. Thus, several previously disconnected processes become a single control loop.

Discussion. The results obtained provide grounds for asserting that the efficiency of community energy resource management increases significantly when geodetic data, digital mapping and automated consumption metering are integrated into a single information environment. This combination of spatial coordinates and technical indicators makes it possible to identify hidden areas of excessive expenditure, local load imbalances and worn-out networks sections in advance, before they lead to emergencies. The practical benefit of the proposed approach is manifested in the transition from reactive repair to predictive service management. As a result, the community receives more accurate budgeting, a more rational distribution of investments and a reduction in operating costs.

Geographic information systems can perform not only a visualisation function, but also the role of an analytical platform for the strategic development of territories. Through multi-criteria site ranking, assessment of project payback, risk modelling and various recovery scenarios, a new logic of local energy planning is formed. It is simultaneously based on spatial feasibility, technical readiness, and social need. This approach appears particularly important for communities undergoing infrastructure modernisation or post-crisis recovery.

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ГЕОІНФОРМАЦІЙНЕ ЗАБЕЗПЕЧЕННЯ ПЛАНУВАННЯ ТА ОБЛІКУ ЕНЕРГЕТИЧНИХ РЕСУРСІВ У ГРОМАДАХ ЯК ІНСТРУМЕНТ ПІДВИЩЕННЯ ЕНЕРГОЕФЕКТИВНОСТІ ТА ЗАБЕЗПЕЧЕННЯ СТАЛОГО РОЗВИТКУ

Анотація. *Стаття визначає методичні засади геоінформаційного супроводу планування та обліку енергетичних ресурсів на рівні територіальних громад. Запропоновано інтегрувати просторові масиви, цифрові реєстри комунальної інфраструктури, системи оперативного моніторингу та аналітичні інструменти управління. Окремо проаналізовано можливості геоінформаційних платформ під час інвентаризації об'єктів, фіксації втрат енергоресурсів та підготовки інвестиційних проєктів. Метою роботи є створення прикладної моделі застосування геоінформаційних технологій у процесі планування, моніторингу та обліку енергоресурсів на рівні громади. Увагу спрямовано на об'єднання відомостей про обсяги споживання, стан інженерних мереж, резерви локальної генерації та ймовірність аварійних* *ситуацій. Дослідження базується на чинних нормативних актах, офіційній статистиці, відкритих геопросторових матеріалах, технічних характеристиках мереж та реєстрах об'єктів комунального господарства. Методологічна частина включає системний аналіз, просторове моделювання, економічне пріоритезування заходів, сценарні розрахунки та порівняльну оцінку управлінських варіантів в сфері енергоспоживання. Автори аргументують необхідність формування єдиної цифрової бази енергетичних ресурсів територіальної громади. У статті представлено інструменти для візуалізації ділянок з надмірним споживанням, розрахунку технічних втрат у мережах та визначення майданчиків для розміщення сонячних, вітрових і біоенергетичних установок. Запропоновано метод відбору інвестиційних проєктів з урахуванням строку окупності, технічної доступності та впливу на довкілля. Доведено ефективність поєднання геоінформаційної системи з лічильниками віддаленого зчитування та місцевим геопорталом. Перспективним напрямом подальшої роботи вважається розробка цифрових двійників муніципальної інфраструктури. Доцільно також дослідити можливості штучного інтелекту у прогнозуванні енергетичних навантажень. Важливим завданням залишається створення галузевих стандартів для обміну просторовими даними.*

Ключові слова: *геоінформаційні системи, енергетичні ресурси, територіальна громада, енергоефективність, просторове планування, сталий розвиток.*