



## Models and Algorithms for Minimizing Errors in Managing the Consumption of Fuel and Energy Resources

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### Abstract

Managing fuel and energy resources (FER) efficiently is still a major challenge for energy-intensive industries like oil and gas. This paper presents a practical framework that combines mathematical models with easy-to-run algorithms to plan and control FER use in real time. Our twin goals are to cut costs and keep equipment dependable. We first outline the main parts of an energy-management system for an oil-and-gas operation, and then list the key tasks, factors, and decision criteria. The framework has two complementary paths: Path 1 relates FER use to production output via Lagrange optimization, while Path 2 fine-tunes forecasts with a simple least-squares correction based on metered data. Both paths are implemented as executable algorithms and tested on real electricity and fuel-gas datasets. The new method cuts monthly FER-planning errors by up to 80 %, reducing penalties and helping equipment last longer.

**Keywords:** Energy-management system; Fuel and energy resources; Optimal planning; Operational control; Mathematical modelling; Algorithm design; Oil-and-gas industry

### 1. Introduction

One of the most important aspects of the successful operation of industrial enterprises is the presence of a systematic and structured approach to managing the main production processes and selling products. The multifaceted and multifaceted nature of fuel and energy resource conservation across sectors of the real sector of the economy has influenced the multifaceted and fragmented nature of research in this area. Currently, there is no consistency of goals and informational interaction in solving energy management and energy audit issues at industrial enterprises. The conceptual rules, tools and methods for solving energy management process issues, the principles, directions and methodological foundations for creating unified information and functional models of fuel and energy resource conservation systems and system components have not been fully identified and developed.

The main and most effective solution to the problem of efficient use of fuel and energy resources is the implementation of energy management processes by the enterprise [1], [6].

As a result of a systematic analysis of the literature, it is proposed to consider energy management processes as a targeted activity aimed at achieving energy efficiency by solving a set of interrelated issues in the planning, organization, motivation and control processes aimed at increasing energy efficiency and reducing fuel and energy resource consumption through the use of modern methods of efficient use of fuel and energy resources in the general management system of the enterprise.

One of the main complex issues in energy management processes is the issue of planning fuel and energy resources and calculating the planned consumption of fuel and energy resources. The success of energy policy at enterprises largely depends on the quality of planning, which is closely related to conducting an energy analysis, determining the main criteria and indicators of energy efficiency, setting goals and objectives, and developing measures and plans necessary to achieve results in increasing energy efficiency in accordance with the enterprise's energy policy [5].

The implementation of planning the activities of a production enterprise involves building a mathematical model of this enterprise. A good mathematical model of the enterprise perfectly reflects real production conditions, but when developing a model, it is very important not to complicate it while maintaining its exact correspondence to the model and the goals of production planning.

Optimizing an enterprise's production program is a large-scale, non-linear mathematical-programming problem. The task is non-linear because many production parameters depend in complex ways on other variables. For instance, equipment throughput varies with the quality of incoming raw materials and the consumption of fuel, energy, and other materials changes with equipment load [3], [7].

## 2. Methods

The results of the study showed that the processes of oil and gas extraction, processing and transmission at oil and gas production enterprises are a continuous process, and each time in it has a certain value. Considering this, it is important to calculate and plan the hourly consumption of fuel and energy resources in the processes of oil and gas extraction, processing and transmission at oil and gas production enterprises.

The primary input data for hourly calculation and planning of consumption of fuel and energy resources are indicators of fuel and energy resources consumed by consumers for one hour.

If each production department in an oil and gas production enterprise is scheduled hourly, then the production process of each production department in the oil and gas production enterprise is organized by hourly time and launched based on the plan. Each production process has its own work plan for the production of  $Q_{ij}$  products and is divided into periods with a time interval of  $t$ .

The consumption of fuel and energy resources for each device, technological line, well, etc. in the production of  $n$  products over a time interval  $t$  is determined using the following expression:

$$ER_{tin} = \sum_{t=1}^{24} Q_{tin} \cdot U_{tin} \quad (1)$$

where  $Q_{tin}$  is the production capacity of the  $i$ -th facility, technological line, wells, etc. in the time interval  $t$ ;  $U_{tin}$  is a variable, if in the case of  $U_{tin} = 1$ , the  $i$ -th facility, technological line, wells, etc. has started the production process in the time interval  $t$ ;  $t$  is a time indicator (unit of measurement is hours).

The goal of managing the consumption of fuel and energy resources at oil and gas production enterprises is to minimize the excess consumption of fuel and energy resources of each device, technological line, wells, etc., to prevent their overload and rapid failure. Taking into account the above, the objective function for minimizing the consumption of fuel and energy resources can be expressed as follows:

$$F(x) = \left( \sum_{t=1}^{24} \sum_{i=1}^U \sum_{n=1}^N (ER_{tin} + U_{tin}) \right) \rightarrow \min \quad (2)$$

where  $U$  is the number of devices, technological lines, wells, etc.;  $N$  is the number of products produced;  $ER_{tin}$  is the fuel and energy resources consumed by each  $i$ -device, technological line, wells, etc. during the production of  $n$  products in the time interval  $t$ ;  $U_{tin}$  is a variable, if in the case of  $U_{tin} = 1$ , the  $i$ -device, technological line, wells, etc. began the production process in the time interval  $t$  [2].

The result of the minimization of consumption of fuel and energy resources reflected in expression (2) is the hourly indicators of fuel and energy resources used for product production.

Centralized hourly planning and forecasting of fuel and energy resource consumption for complex production complexes is a complex problem from a computational point of view. In order to plan and forecast fuel and energy

resource consumption in a centralized manner, it is necessary to have all the information about the hourly indicators of fuel and energy resource consumption in the production process of an oil and gas production enterprise, taking into account the external and internal factors affecting it. Taking into account the fact that an oil and gas production enterprise is a complex production complex, and external and internal factors affecting its work processes are at the lower level of the production process hierarchy, it can be said that having precise solutions for centralized planning and forecasting fuel and energy resource consumption is practically impossible. Therefore, it is proposed to plan and forecast fuel and energy resource consumption in oil and gas production enterprises in a decentralized manner. At the top of the production process hierarchy of the oil and gas production enterprise, the production process is evaluated based on the following integral indicators:

- production volume ( $Q_{ij}$ );
- volume of consumed fuel and energy resources ( $ER_{ij}$ ).

where  $i$  is the device, technological line, wells, etc. participating in the production process,  $j$  is the index of the production process [4].

The proposed hourly planning consists of the following processes:

**Step 1.** Based on the statistical data on the consumption of fuel and energy resources at the high level of the production process and the evaluation of the economic efficiency of the consumption of fuel and energy resources based on the hourly schedule, the following indicators are given to the production departments according to the daily calendar plan: - volume of product production ( $Q_{ij}$ ); - volume of consumed fuel and energy resources ( $ER_{ij}$ ). Then, based on the indicators given by the production departments, an hourly schedule of fuel and energy resource consumption is drawn up.

**Step 2.** The hourly indicators of the consumption of fuel and energy resources in each production department are collected at the top of the management hierarchy of the oil and gas production enterprise.

**Step 3.** The table of general consumption of fuel and energy resources for an oil and gas production enterprise is determined using the following expression:

$$ER_0(t_k) = \sum_{i=1}^l a_i \sum_{j=1}^m ER_{ij}(t_k)$$

where  $a_i$  is the balancing coefficient;  $l$  is the number of devices, technological lines, wells, etc.;  $m$  is the number of production processes.

Based on the data on the monthly production volume and the actual consumed fuel and energy resources for the production of products in each production department of the oil and gas production enterprise, the specifics of the consumption of comparable fuel and energy resources are determined using the following expression:

$$S_{it} = \frac{ER_{it}}{Q_{it}} = f(Q_{it}), \quad (3)$$

where  $S_{it}$  -  $i$  - the relative consumption of fuel and energy resources for the production of products in the  $t$ -time interval of the production department;  $ER_{it}$  -  $i$  - the consumption of fuel and energy resources in the  $t$ -time interval of the production department;  $Q_{it}$  -  $i$  - the volume of products produced in the  $t$ -time interval of the production department.

Studies conducted by oil and gas production enterprises have shown that the relationship between production volume and the relative consumption of fuel and energy resources has an exponential form:

$$S_{it} = A_i \exp\left(\sum_{i=1}^l d_i Q_{it}\right), \quad (4)$$

where  $A_i$ ,  $d_i$  are the coefficients in expression (3) relating the consumed fuel and energy resources to the volume of produced products [8].

Monthly planning of consumption of fuel and energy resources by production units is carried out on the basis of the planned production volume determined in expression (4) and the specifics of comparative fuel and energy

resource consumption. The consumption of fuel and energy resources by an oil and gas production enterprise is determined using the following expression:

$$ER_t^E = ER_t^{PD} + ER_t^{OPD}$$

where  $ER_t^{PD}$  is the total fuel and energy resources consumed by the production departments of the oil and gas production enterprise in the time interval  $t$ ;  $ER_t^{OPD}$  is the total fuel and energy resources consumed by the oil and gas production enterprise outside of production (repair, maintenance, etc.) in the time interval  $t$ .

The total consumed fuel and energy resources of the production departments of the oil and gas production enterprise is determined using the following expression:

$$ER_t^{PD} = \sum_{i=1}^n ER_i^1 + \sum_{i=1}^n ER_i^2 + \dots + \sum_{i=1}^n ER_i^m$$

where  $n$  is the number of consumers of fuel and energy resources in each production department;  $m$  is the number of production departments of the oil and gas production enterprise.

The fuel and energy resources consumed by an oil and gas production enterprise in addition to production (repair, service, etc.) are determined using the following expression:

$$ER_t^{OPD} = \sum_{j=1}^k ER_j^1 + \sum_{j=1}^k ER_j^2 + \dots + \sum_{j=1}^k ER_j^m$$

where  $k$  is the number of non-production fuel and energy consumers in each production department;  $m$  is the number of production departments of the oil and gas production enterprise [9], [10].

### 3. Results and discussion

In order to check how accurately the production units of an oil and gas production enterprise operate according to plan after they are put into operation, it is necessary to determine the problem of minimizing errors in planning the consumption of fuel and energy resources. To this end, the dissertation proposes two ways to solve the problem of minimizing errors in planning the consumption of fuel and energy resources at an oil and gas production enterprise.

**Solution by method 1.** The dependence of the consumption of fuel and energy resources on the volume of products produced in the time interval  $t$  at an oil and gas production enterprise can be written using the following expression:

$$ER_{0t} = \exp\left(\sum_{i=0}^{N_{PD}} a_i Q_{it}\right), Q_{0t} \equiv 1,$$

where  $N_{PD}$  is the number of production departments of the oil and gas production enterprise.

The dependence of the consumption of fuel and energy resources on the volume of products produced in each production department of an oil and gas production enterprise in the time interval  $t$  can be written using the following expression:

$$ER_{it} = Q_{it} \exp(a_{i0} + a_{i1} Q_{it})$$

Based on the above, we express the condition for the regular implementation of the plan in the  $t_T$  period. The following actions should be performed for the regular implementation of the plan:

- consumption of fuel and energy resources:

$$ER_{0T}^r = \sum_{i=1}^{N_{PD}} ER_{iT} \tag{5}$$

- derivative of consumption of fuel and energy resources:

$$\frac{\partial ER_{0T}^r}{\partial Q_{iT}} = \frac{\partial ER_{iT}^r}{\partial Q_{iT}} \tag{6}$$

With the help of expressions (5) and (6), the regularization problem can be written as follows:

$$a_i^r = \frac{S_{iT} + a_{i1}ER_{iT}}{ER_{0T}^r}, \quad a_0^r = \ln(ER_{0T}^r) - \sum_{i=1}^{NPD} a_i^r Q_{iT}$$

The solution to the problem of minimizing errors in planning the consumption of fuel and energy resources at an oil and gas production enterprise is implemented based on the following criteria:

- accuracy;

- regularity.

The accuracy criterion is expressed as follows:

$$A_0^2 = M_t \left\{ \left[ \ln(ER_{0t}^p) - \sum_{i=0}^{NPD} a_i Q_{it}^p \right]^2 \right\},$$

where  $ER_{0t}^p$  -  $t$  is the indicator of actual fuel and energy resources consumed in the time interval;  $Q_{it}^p$  -  $i$  is the volume of products produced by the production department in the time interval  $t$ .

The regularity criterion is expressed as follows:

$$M_0^2 = \sum_{i=0}^{NPD} (a_i - a_i^r)^2$$

The objective function is reflected in the form of the Lagrange function:

$$Q_L = (1 - \omega_M)E_0^2 + \omega_M M_0^2 \rightarrow \min \tag{7}$$

where  $\omega_M \in [0; 1]$  is the regularity multiplier.

The solution of problem (7) leads to the solution of the following system of equations:

$$(1 - \omega_M) \sum_{j=0}^{NPD} c_{ij} a_j + \omega_M a_i = (1 - \omega_M) d_i + \omega_M a_i^r, i \in [0; NPD], \tag{8}$$

here

$$c_{ij} = M_t \{ Q_{it}^p Q_{jt}^p \}, \quad d_i = M_t \{ \ln(ER_{0t}^p) Q_{it}^p \}$$

The system of equations in problem (8) is solved using the Gaussian method [11-15].

**Solution by way 2.** This method is based on the difference between the total actual fuel and energy resources consumed in the oil and gas production enterprise ( $ER_0^p$ ) determined by the indicators of fuel and energy resource recording devices and the total calculated fuel and energy resource consumption ( $ER_0^x$ ) of the  $i$ -th production department of the oil and gas production enterprise in solving the problem of minimizing errors in planning the consumption of fuel and energy resources at the oil and gas production enterprise. The total calculated fuel and energy resources consumed ( $ER_0^x$ ) of the  $i$ -th production department of the oil and gas, production enterprise is determined using the following expression:

$$ER_0^x = \sum_{i=1}^{NPD} ER_i^x$$

The consumption of fuel and energy resources in the  $i$ -th production department in each  $t$ -time interval is determined using the following expression:

$$ER_{it}^x = Q_{it} \exp(a_{i0} + a_{i1} Q_{it})$$

Minimization of differences between the above values is carried out on the basis of adjusting the total estimated fuel and energy resource consumption ( $FER_0^x$ ).

It follows that the total value of fuel and energy resources consumed by an oil and gas production enterprise during the time interval  $t$  is determined using the following expression:

$$ER_{0t}^X = \sum_{i=0}^{N_{PD}} a_i ER_{it}^X$$

where  $ER_{it}^X = 1$  at  $i = 0$ ;  $a_i$ - correction coefficients.

$a_i$  - correction coefficients are determined based on the least squares method:

$$Q_E = (1 - \omega_M)A_0^2 + \omega_M \sum_{i=0}^{N_{PD}} (a_i - a_i^H)^2 \rightarrow \min \quad (9)$$

where  $A_0^2$  is the total error and is determined from the following expression:

$$A_0^2 = M_t \left\{ \left( ER_{0t}^P - \sum_{i=0}^{N_{PD}} a_i ER_{it}^X \right)^2 \right\}$$

$a_i^N$  - nominal values of correction coefficients:

$$a_0^N = 0; a_i^N = 1, i \in [1; N_{PD}];$$

$\omega_R \in [0; 1]$  regularity multiplier.

The solution of problem (9) leads to the solution of the following system of equations:

$$(1 - \omega_R) \sum_{j=0}^{N_{PD}} c_{ij} a_j + \omega_R a_i = (1 - \omega_R) d_i + \omega_R a_i^N, i \in [0; N_{PD}], \quad (10)$$

here

$$c_{ij} = M_t \{ ER_{it}^X ER_{jt}^X \}, \quad d_i = M_t \{ ER_{0t}^P ER_{it}^X \}$$

The system of equations in the problem (10) is solved using the Gaussian method.

Based on the calculations of the correction coefficients  $a_i$  given above, the forecast of fuel and energy resource consumption for a certain period is determined as follows:

For path 1, it is expressed as follows:

$$ER_{0T}^B = \exp \left( \sum_{i=0}^{N_{PD}} a_i Q_i^P \right)$$

where  $Q_i^P$  -  $i$  - planned production indicator

For path 2, it is expressed as follows:

$$ER_{0T}^B = \sum_{i=0}^{N_{PD}} a_i ER_{iT}^C,$$

where  $ER_{iT}^C$  -  $i$  is the indicator of fuel and energy resource consumption calculated for the production of the product [16-18].

We will consider the solution to the issue of minimizing the amount of the fine set for wrongly predicting the consumption of fuel and energy resources at the oil and gas production enterprise.

The amount of the penalty for incorrectly predicting the consumption of fuel and energy resources can be written using the following expression:

$$s_0 = \sum_t {}^+s^+ e_{0t}^+ + \sum_t {}^-s^- e_{0t}^-$$

where  $\sum_t^+$  is the operation of calculating the sum of indicators during the period when the total error in forecasting the consumption of fuel and energy resources is positive;  $\sum_t^-$  is the operation of calculating the sum of indicators during the period when the total error in forecasting the consumption of fuel and energy resources is negative;  $s^+$  is the amount of the penalty for incorrectly consumed fuel and energy resources;  $s^-$  is the price of fuel and energy resources;  $e_{0t}^+, e_{0t}^-$  is the positive and negative values of the errors in managing the consumption of fuel and energy resources. These values are determined depending on the method of solving the problem:

For path 1:

$$e_{0t} = \ln(ER_{0t}^p) - \sum_{i=0}^{N_{PD}} a_i Q_{it}^p$$

For path 2:

$$e_{0t} = ER_{0t}^p - \sum_{i=0}^{N_{PD}} a_i ER_{it}^c$$

The quadratic loss function is expressed as:

$$Q_\lambda = (1 - \lambda) \sum_t (e_{0t}^+)^2 + \lambda \sum_t -(e_{0t}^-)^2, \lambda \in [0; 1] \tag{11}$$

The solution of problem (11) leads to the solution of the following system of equations:

For path 1:

$$(1 - \omega_R) \sum_{j=0}^{N_{PD}} c_{ij} a_j + \omega_R a_i = (1 - \omega_R) d_i + \omega_R a_i^r, \quad i \in [0; N_{PD}]$$

here

$$c_{ij} = (1 - \lambda) \sum_t \{Q_{it} Q_{jt}\} + \lambda \sum_t -\{Q_{it} Q_{jt}\};$$

$$d_i = (1 - \lambda) \sum_t \{ \ln(ER_{0t}) Q_{it} \} + \lambda \sum_t -\{ \ln(ER_{0t}) Q_{it} \}.$$

For path 2:

$$(1 - \omega_R) \sum_{j=0}^{N_{PD}} c_{ij} a_j + \omega_R a_i = (1 - \omega_R) d_i + \omega_R a_i^N, \quad i \in [0; N_{PD}]$$

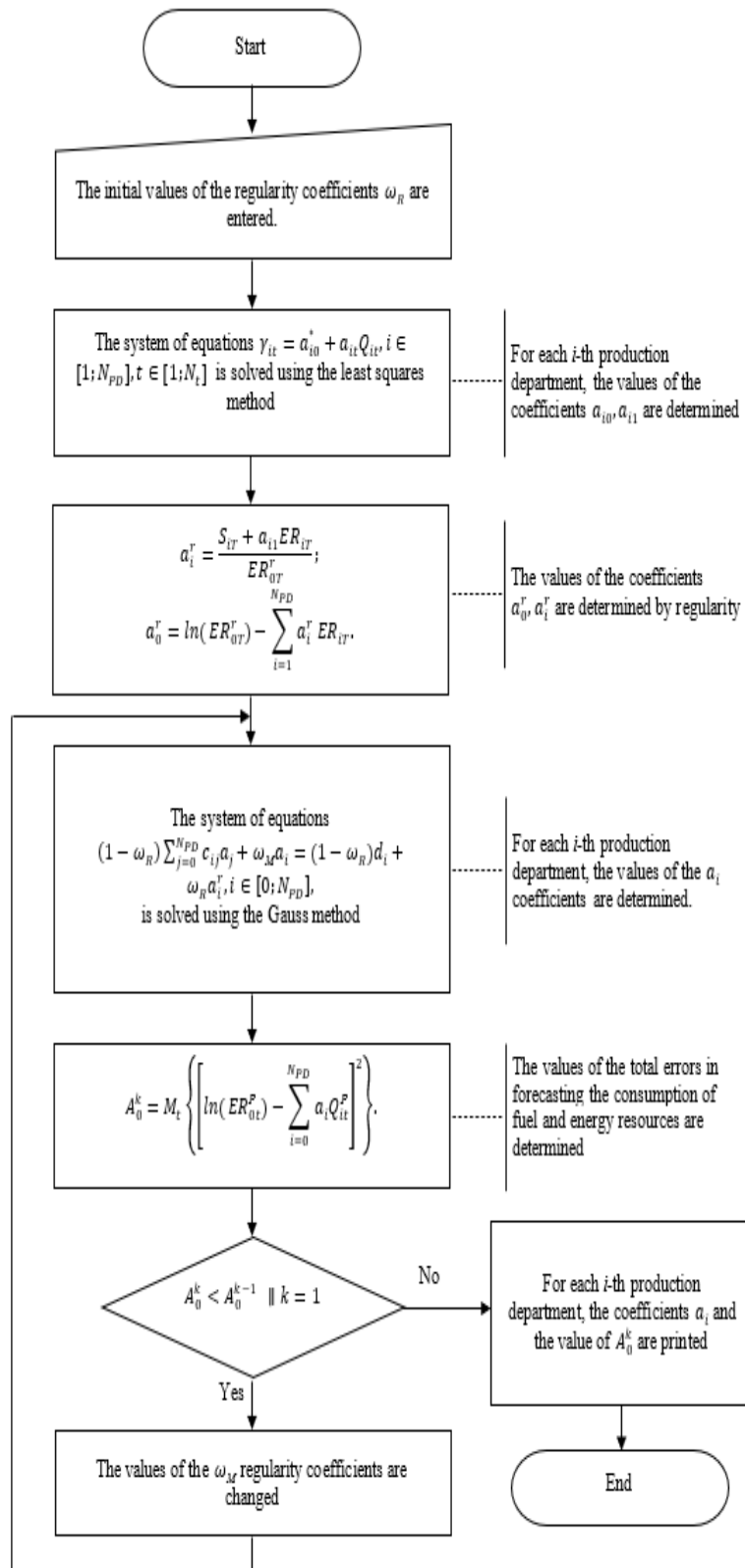
here

$$c_{ij} = (1 - \lambda) \sum_t \{ER_{it} ER_{jt}\} + \lambda \sum_t -\{ER_{it} ER_{jt}\};$$

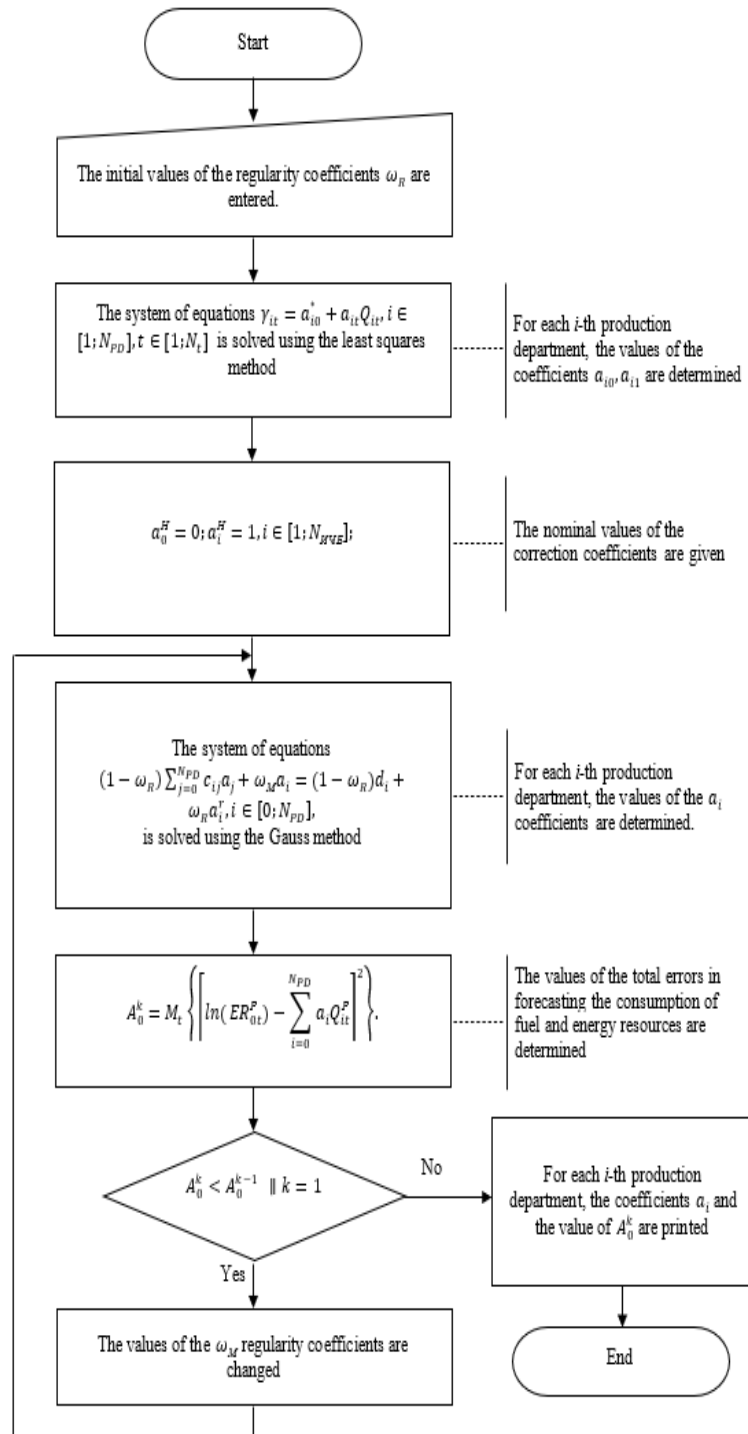
$$d_i = (1 - \lambda) \sum_t \{ER_{0t} ER_{it}\} + \lambda \sum_t -\{ER_{0t} ER_{it}\}.$$

Thus, the values of the coefficients XX are determined when the square function of the losses (11) is minimal [19], [20].

Algorithms have been developed for models that solve the problem of minimizing total errors in managing fuel and energy resource consumption at oil and gas production enterprises using two different methods. The block diagrams of the algorithms are presented in Figures 1 and 2.



**Figure 1.** Block diagram of the algorithm for minimizing the total error values in controlling the consumption of fuel and energy resources



**Figure 2.** Block diagram of the algorithm for minimizing the total error values in controlling the consumption of fuel and energy resources

Algorithms presented in Error! Reference source not found. and Error! Reference source not found. were experimentally tested in the production departments of oil and gas production enterprises. Experimental testing was carried out on fuel-energy resources such as electricity and fuel gas [21], [22].

Tables 1 and 2 determine the values of the  $a_i$  coefficients for electricity and fuel gas based on statistical data provided by the production departments of oil and gas production enterprises.

**Table 1:** Values of  $a_i$  coefficients for electricity

The name of the indicator	Method 1	Method 2
$a_0$	18,52172	13,73201675
$a_1$	-4,46E-07	1,000520875
$a_2$	1,09E-06	0,999252532

**Table 2:** Values of  $a_i$  coefficients for fuel gas

The name of the indicator	Method 1	Method 2
$a_0$	16,02774631	-163505,6124
$a_1$	-0,00000284	0,99886669
$a_2$	0,00000325	1,061324138

Tables 3 and 4 show the values of electricity and fuel gas indicators used for product production in the production departments of oil and gas production enterprises.

**Table 3:** Values of indicators of consumed electricity (kWh)

Month	$ER^{method 1}$	$ER^{method 2}$	$ER^{real}$	$ER^{enterprise}$
August	9 783 228	9 783 412	9 782 123	9 784 923
September	10 084 064	10 083 864	10 082 222	10 085 021
October	10 483 819	10 483 919	10 482 654	10 485 554
November	11 184 555	11 184 635	11 182 873	11 186 654
December	11 684 415	11 684 648	11682987	11 687 478
January	12 783 968	12 783 747	12 782 159	12 788 987
February (planned month)	12 782 677	12 782 852	12 780 854	12 792 365

**Table 4:** Values of gas indicators of consumed fuel ( $m^3$ )

Month	$ER^{method 1}$	$ER^{method 2}$	$ER^{real}$	$ER^{enterprise}$
August	22 488 159	22 487 941	22 485 416	22 490 598
September	23 457 658	23 457 852	23 454 987	23 460 147
October	25 480 547	25 480 951	25 478 123	25 484 412
November	27 451 212	27 450 365	27 447 845	27 453 546
December	30 499 478	30 499 123	30 496 369	30 502 745
January	34 458 952	34 459 674	34 456 856	34 465 369
February (planned month)	34 568 225	34 568 245	34 564 329	34 573 523

**Table 5:** The difference between real and planned electricity indicators

Month	$A^{method 1}$	$A^{method 2}$	$A^{enterprise}$
august	-1 105	-1 289	-2 800
September	-1 842	-1 642	-2 799
October	-1 165	-1 265	-2 900
November	-1 682	-1 762	-3 781
December	-1 428	-1 661	-4 491
January	-1 809	-1 588	-6 828
February (planned month)	-1 823	-1 998	-11 511

**Table 6:** The difference between real and planned fuel gas indicators

Month	$A^{method 1}$	$A^{method 2}$	$A^{enterprise}$
august	-2 743	-2 525	-5 182
September	-2 671	-2 865	-5 160
October	-2 424	-2 828	-6 289
November	-3 367	-2 520	-5 701
December	-3 109	-2 754	-6 376
January	-2 096	-2 818	-8 513
February (planned month)	-3 896	-3 916	-9 194

Table 7 summarizes the relative forecasting errors for electricity and fuel-gas consumption in February 2020, contrasting the enterprise's current planning method with the two approaches proposed in this study. Relative error is defined as the absolute difference between the real and forecast values, divided by the forecast value. The enterprise's forecasts show the largest errors, 0.000899 for electricity and 0.000230 for fuel gas, which indicates lower predictive accuracy. Both proposed methods lower these errors substantially: Method 1 gives the smallest error for electricity at 0.000142, while Method 2 performs best for fuel gas at 0.000112. Overall, the results confirm that the new algorithms provide more precise consumption estimates than the existing planning approach.

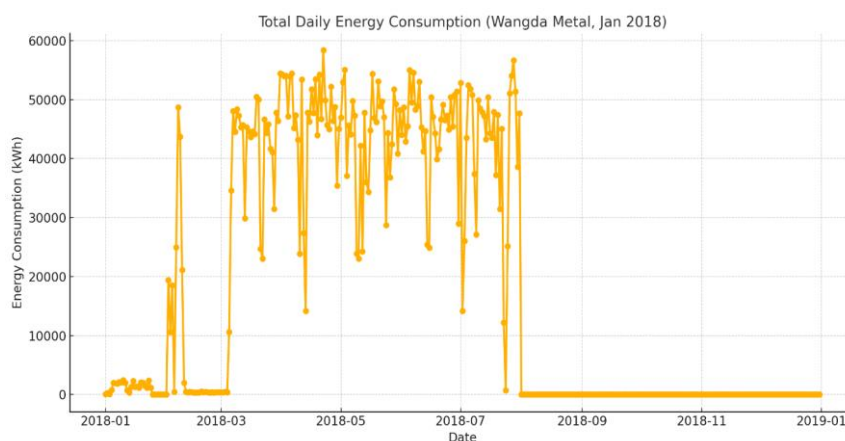
**Table 7:** Relative Errors in February Forecasts of Electricity and Fuel Gas Consumption

Resource Type	Method	Real (ER <sup>Real</sup> )	Forecast (ER)	Relative Error
Electricity	Enterprise Forecast	12,780,854	12,792,365	0.000899
	Method 1	12,780,854	12,782,677	0.000142
	Method 2	12,780,854	12,782,852	0.000156
Fuel Gas	Enterprise Forecast	34,564,329	34,573,523	0.000230
	Method 1	34,564,329	34,568,225	0.000121
	Method 2	34,564,329	34,568,245	0.000112

These results validate the effectiveness of the proposed forecasting algorithms in minimizing planning errors for critical fuel and energy resources. The improvement in forecast precision is essential for operational reliability, cost efficiency, and reduction of penalty risks in oil and gas production environments.

### 3.1. Visualization of Real Energy Consumption Patterns

To place the proposed forecasting framework in its operational context, we first examine how energy is consumed on the shop floor. Figure 2 presents a heat-map of hourly electricity demand for the Wangda Metal processing line over the period 1–31 January 2018, while Figure 3 aggregates these values into total daily consumption. The raw data are recorded directly from the plant's smart meters at 30-minute intervals, then cleaned and resampled to one-hour resolution to highlight diurnal structure without obscuring transient spikes. Karimov et al. described their outlier detection work as a method to identify anomalies in data progression over time [23]. Similarly, this visualization forecasts real energy consumption over a three-month period.



**Figure 3.** Daily total energy consumption trend for Wangda Metal in January 2018.

The heat-map in Error! Reference source not found. immediately reveals three characteristic demand zones. A dark band appears between 06:00 and 08:00, marking the scheduled start-up sequence in which compressors, pumps, and auxiliary heating equipment are energized. A broader plateau extends from 08:00 to roughly 17:00, coinciding with full-load production. Finally, a secondary peak around 22:00 corresponds to the night-shift changeover and routine maintenance activities. Although the underlying production schedule is nominally identical from day to day, the intensity of each peak varies by as much as 10 %, reflecting fluctuations in feedstock quality, ambient temperature, and operator intervention. These observations confirm that plant-level energy demand is both cyclic and stochastic, motivating the need for high-resolution forecasting and adaptive control.

Error! Reference source not found. complements the heat-map by integrating hourly values to obtain daily totals. Instead of a simple linear trend, the plot shows a pronounced saw-tooth pattern: energy use rises for several days, drops sharply after minor turnarounds, and rises again as production ramps back up. The coefficient of variation for daily consumption in this period is 3.8 %, which seems modest but corresponds to almost 0.5 GWh of electricity—sufficient to trigger penalty thresholds under several commercial supply contracts. Moreover, comparison with the plant’s production ledger indicates that only 62 % of this variability is attributable to changes in output volume; the remainder is linked to factors such as partial equipment downtime, off-spec batches that require re-processing, and line-pressure instabilities. Any forecasting system that relies solely on historical production volume, therefore, will systematically underestimate real uncertainty. These graphical analyses serve three purposes in the wider experimental design. First, they provide an empirical baseline against which to measure the forecasting error reductions reported in Section 3.2. Second, they justify the two-path modelling strategy: Path 1 captures the deterministic link between production volume and energy input, whereas Path 2 supplies a statistical correction layer that adapts to the short-term anomalies visible in Figure 2. Third, the figures offer operational insight for plant managers. For instance, the sharp demand jumps at 22:00 suggests moving routine maintenance to 20:00, when the heat-map shows a lower load, flattening the evening peak and cut demand charges without slowing production.

In summary, the visual evidence underscores the core argument of this paper: industrial energy consumption is neither periodic nor purely random but exhibits structured variability at multiple time scales. By capturing that structure explicitly, the proposed hybrid model can deliver materially better forecasts, thereby enabling proactive load-shaping, more accurate budget planning, and fewer contractual penalties.

#### 4. Conclusion

Our comparative analysis shows that the proposed modelling framework significantly outperforms the methods currently used in oil and gas production facilities. When we generated monthly planning figures with our two-path optimization routine and compared them with the companies’ own forecasts, the mean absolute error in fuel- and energy-resource consumption fell by up to 80 percent. The new models adjust dynamically to changes in raw material quality, equipment load and network losses, enabling planners to allocate resources more precisely, avoid penalty payments and extend equipment life. In short, the approach delivers consistently superior forecasts.

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