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MODELLING AND OPTIMIZING MATERIAL FLOWS IN ELECTRICAL ENERGY DISTRIBUTION – FIRST MODEL

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Abstract: *The paper focuses on modelling and optimizing the distribution of material flows in a first version. Furthermore, the focus is on electrical energy flows, considering different energy sources and types of consumers. The most commonly used energy sources are nuclear, thermal, renewable and geothermal. The main categories of consumers include industry, residential, commercial and, increasingly, electric transportation. A first model is proposed which uses matrices for the various time constraints and uses graph theory to represent the flow of energy between sources and consumers. Variables and constraints are established to ensure that the flow remains within maximum capacities and meets minimum demands. In addition, a first version of mathematical model is proposed to minimize total energy supply costs.*

Keywords: *optimization, energy flow, material flows*

1. INTRODUCTION

Global energy consumption has been steadily increasing due to the growing global population, rapid industrialization, and advancements in technology. This surge in energy usage has significant implications for the environment, as it leads to increased carbon emissions and the depletion of natural resources. In response to this, European countries have been making efforts to transition towards more sustainable energy sources, such as solar and wind power. Hungary, as one of the major consumers of energy in Europe taking the population ratio into account, has been working towards diversifying its energy mix and increasing the use of renewable sources.

This shift towards clean energy technologies has been supported by policy initiatives and investments in the development of renewable energy infrastructure. Furthermore, mathematical models involving matrices have become essential tools in analyzing complex systems and solving equations in various fields of research and industry. These models are used to study and predict energy consumption patterns, optimize energy production, and improve the efficiency of energy distribution systems.

As the global demand for energy continues to rise, it is crucial for countries to prioritize the development and adoption of sustainable energy solutions. This includes investing in renewable energy sources, improving energy efficiency, and promoting the use of clean technologies. By doing so, we can mitigate the environmental impact of our energy consumption and ensure the availability of natural resources for future generations.

In the second section of this paper, the background of material flow and electric energy system is written. For describing this material flow system, a mathematical matrix model is used during this research, which is discussed in the second half of this paper.

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2. BACKGROUND AND FIRST MODEL

The flow of materials, logistics, and electrical energy are crucial components of modern industrial and commercial operations. The efficient movement of raw materials, components, and finished products is essential for ensuring the smooth functioning of supply chains and manufacturing processes. Logistics involves the coordination of these movements, as well as the management of storage, transportation, and distribution activities. Meanwhile, electrical energy is a fundamental requirement for powering machinery, equipment, and lighting systems in various industrial and commercial settings. Together, these three elements play a vital role in supporting the operations of businesses and industries worldwide.

2.1. Material flow and energy

Material flow refers to the movement and transfer of materials through a system or process. It can be applied to a variety of contexts, such as waste management, the supply chain in industry, or even biogeochemical cycles in nature. It is important in environmental management and resource efficiency, as it allows tracking how materials enter, are use and leave a system, which can help optimize resource use and minimize waste.

Several authors define the development of material flow in global logistics has been instrumental in the evolution of industry and trade globally [1-5]. Here are some key aspects:

1. Globalization.
2. Technology.
3. Supply chain efficiency.
4. Multimodal transportation.
5. Sustainability.
6. E-commerce.

The flow of materials in global logistics has evolved significantly as companies have sought ways to optimize their operations, reduce costs and meet the demands of a globalized and ever-changing marketplace.

The flow of materials and energy are interconnected in multiple aspects according to the following authors [6-11] as follows:

1. Extraction and production of materials.
2. Transportation.
3. Warehousing.
4. Recycling and materials recovery.
5. Energy efficiency.
6. Renewable energy.

The flow of materials in logistics and industry has a direct impact on energy consumption, and efficiency in managing this flow can contribute to the reduction of energy use and environmental sustainability. Adopting more efficient and sustainable practices at all stages of the process can minimize environmental impact [12].

2.2. The energy in Hungary

The flow of materials and energy in Hungary is influenced by various economic, geographical and environmental factors. The flow of materials in Hungary is best represented in the following three areas: industry, foreign trade and agriculture. Hungary is an industrialized country with significant production in sectors such as automobile, chemical and machinery manufacturing. This implies a constant flow of raw materials and finished products through its logistics network. Given its role in the European Union, Hungary is involved in international trade, importing and exporting a variety of products. The flow of materials is related to the import of raw materials and the export of manufactured goods. Agriculture also contributes to the flow of materials, as the country produces a variety of agricultural products and foodstuffs that require transportation and distribution [13], [14].

Hungary has a nuclear power plant at Paks, which is the country's main source of energy. It also uses thermal power plants that burn natural gas and coal to generate electricity and heat. These plants are responsible for a significant part of the country's power generation. Hungary is gradually increasing its renewable energy capacity. Renewable energy sources used include hydropower, solar power and wind power. While these sources still account for a small share of total power generation in the country, they are expected to increase in the coming years. In addition, it takes advantage of the country's geothermal potential to generate electricity and heat. Geothermal wells are used to extract heat from underground and convert it into usable energy.

Hungary has had a long history with low-carbon energy. In the 1980s, there was a steady increase in nuclear power generation from 2.3 TWh in 1983 to a peak of 3.6 TWh in 1987. However, nuclear power generation experienced a decline in 2003 before beginning to recover in 2004. Since then, electricity generated through nuclear sources has shown steady growth. Figure 1 shows how over the last two decades, there has been a boom in solar power with electricity generation increasing from 0.8 TWh in 2019 to 1.3 TWh in 2021.

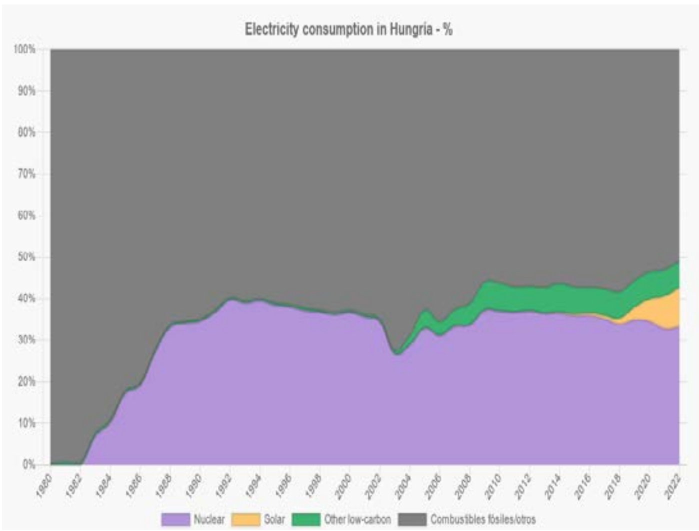

Figure 1. Electricity consumption in Hungary % [12]

In 2022, Hungary's electricity generation and consumption had an interesting mix of low-carbon and fossil fuel energies. Nearly half (49.07%) of the electricity was of low-carbon origin, with nuclear power being the main source supplying more than a third (33.26%) of the total. Fossil fuels supplied a quarter of electricity with gas (18.59%) and coal (6.09%) being the most significant. Solar energy was the second low carbon energy source with 9.38%, followed by. Biofuels with 4.72%. Wind and hydroelectric power contributed little adding only about 1.68% in total. In turn, net electricity imports in Hungary accounted for 25.46% of electricity consumption, reaching a peak net import of 60% during the period.

2.3. Mathematical Matrix Model

For describing the material flow and electrical energy system a mathematical matrix model is used during this research. This mathematical model examines basically the consumption or production in time. To create a mathematical matrix model for bar charts that includes start time, end time, and energy consumption, you can use a matrix in which each row represents a time interval and the columns contain information about the start of the time interval, the end of the time interval, and the energy consumption during that interval. A mathematical matrix model for making bar charts can be represented as follows:

Let be a matrix F of size $n\ x\ m$, where n represents the number of categories or variables to be plotted and m represents the number of bars in the graph.

Each element of the matrix F_1, denoted as $m\ (i,j)$, represents the height of the bar corresponding to category i and bar j.

$$F_1 = \begin{matrix} \\ 1 \\ 2 \\ 3 \\ \vdots \\ i \\ \vdots \\ n_f \end{matrix} \begin{matrix} \begin{matrix} 1 & 2 & \dots & m_j \end{matrix} \\ \begin{bmatrix} m_{1,1} & m_{1,2} & \dots & m_{1,j} \\ m_{2,1} & m_{2,2} & \dots & m_{2,j} \\ m_{3,1} & m_{3,2} & \dots & m_{3,j} \\ \cdots & \cdots & \dots & \vdots \\ m_{i,1} & m_{i,2} & \dots & m_{i,j} \\ \cdots & \cdots & \dots & \vdots \\ m_{n_f,1} & m_{n_f,1} & \dots & m_{n_f,j} \end{bmatrix} \end{matrix} \tag{1}$$

where each element $F_1\ (i,j)$ represents the energy consumption of category i at bus j.

The matrix F_2 would represent the initial time:

$$F_2 = \begin{matrix} \\ 1 \\ 2 \\ 3 \\ \vdots \\ i \\ \vdots \\ n_f \end{matrix} \begin{matrix} \begin{matrix} 1 & 2 & \dots & t_{i_j} \end{matrix} \\ \begin{bmatrix} ti_{1,1} & ti_{1,2} & \dots & ti_{1,j} \\ ti_{2,1} & ti_{2,2} & \dots & ti_{2,j} \\ ti_{3,1} & ti_{3,2} & \dots & ti_{3,j} \\ \cdots & \cdots & \dots & \vdots \\ ti_{i,1} & ti_{i,2} & \dots & ti_{i,j} \\ \cdots & \cdots & \dots & \vdots \\ ti_{n_f,1} & ti_{n_f,1} & \dots & ti_{n_f,j} \end{bmatrix} \end{matrix} \tag{2}$$

where each element $F_2(i,j)$ represents the initial time of category i at bar j.

The matrix F_3 would represent the final time:

$$F_3 = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ \vdots \\ i \\ \vdots \\ n_f \end{array} \begin{array}{c} \begin{array}{cccc} 1 & 2 & \dots & t_{f_j} \end{array} \\ \begin{bmatrix} t_{f1,1} & t_{f1,2} & \dots & t_{f1,j} \\ t_{f1,2} & t_{f2,2} & \dots & t_{f2,j} \\ t_{f3,1} & t_{f3,2} & \dots & t_{f3,j} \\ \dots & \dots & \dots & \vdots \\ t_{fi,1} & t_{fi,2} & \dots & t_{fi,j} \\ \dots & \dots & \dots & \vdots \\ t_{fn_f,1} & t_{fn_f,1} & & t_{fn_f,j} \end{bmatrix} \end{array} \tag{3}$$

where each element $F_3(i, j)$ represents the final time for category i at bar j.

These matrices can be used to generate bar charts representing the energy consumption, start time and end time of different categories or variables. Each column of the matrices would represent a bar in the graph, while each row would represent a category or variable. Figure 2 show the graphs of consumption over time for the consumers.

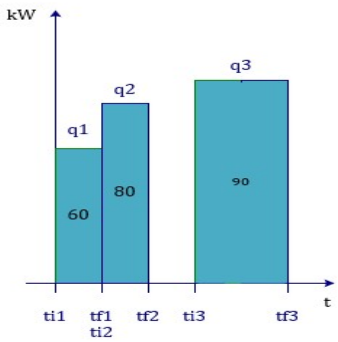

Figure 2. Electricity consumption (self-made)

The mathematical matrix model for making bar charts can be adapted to represent the sources of energy generation, the initial time and the final time of different categories or variables.

It should be supposed that we want to plot the power generation sources, start time and end time of G_i different categories ($n = i$) on a graph with j bars ($m = j$). We could use 3 matrices G_1, G_2 and G_3, each of size $n\ x\ m$, to represent these data.

Matrix $G1$ would represent the sources of power generation:

$$G_1 = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ \vdots \\ i \\ \vdots \\ n_f \end{array} \begin{array}{c} \begin{array}{cccc} 1 & 2 & \dots & y_j \end{array} \\ \begin{bmatrix} y_{1,1} & y_{1,2} & \dots & y_{1,j} \\ y_{2,1} & y_{2,2} & \dots & y_{2,j} \\ y_{3,1} & y_{3,2} & \dots & y_{3,j} \\ \dots & \dots & \dots & \vdots \\ y_{i,1} & y_{i,2} & \dots & y_{i,j} \\ \dots & \dots & \dots & \vdots \\ y_{n_f,1} & y_{n_f,1} & & y_{n_f,j} \end{bmatrix} \end{array} \tag{4}$$

where each element $G_1(i, j)$ represents the amount of energy generated by source i at bar j. The matrix G_2 would represent the initial time:

$$G_2 = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ \vdots \\ i \\ \vdots \\ n_f \end{array} \begin{array}{c} \begin{array}{cccc} 1 & 2 & \dots & t_{i_j} \end{array} \\ \begin{bmatrix} ti_{1,1} & ti_{1,2} & \cdots & ti_{1,j} \\ ti_{2,1} & ti_{2,2} & \cdots & ti_{2,j} \\ ti_{3,1} & ti_{3,2} & \cdots & ti_{3,j} \\ \cdots & \cdots & \cdots & \vdots \\ ti_{i,1} & ti_{i,2} & \cdots & ti_{i,j} \\ \cdots & \cdots & \cdots & \vdots \\ ti_{n_f,1} & ti_{n_f,1} & & ti_{n_f,j} \end{bmatrix} \end{array} \qquad (5)$$

Where each element $G_2(i, j)$ represents the initial time of source i at bar j.

Matrix G_3 would represent the final time:

$$G_3 = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ \vdots \\ i \\ \vdots \\ n_f \end{array} \begin{array}{c} \begin{array}{cccc} 1 & 2 & \dots & t_{f_j} \end{array} \\ \begin{bmatrix} t_{f1,1} & t_{f1,2} & \cdots & t_{f1,j} \\ t_{f1,2} & t_{f2,2} & \cdots & t_{f2,j} \\ t_{f3,1} & t_{f3,2} & \cdots & t_{f3,j} \\ \cdots & \cdots & \cdots & \vdots \\ t_{fi,1} & t_{fi,2} & \cdots & t_{fi,j} \\ \cdots & \cdots & \cdots & \vdots \\ t_{fn_f,1} & t_{fn_f,1} & & t_{fn_f,j} \end{bmatrix} \end{array} \qquad (3)$$

where each element $G_3(i, j)$ represents the end time of source i at bar j.

These matrices can be used to generate bar charts representing the sources of energy generation, the initial time and the final time of the different categories or variables. Each column of the matrices would represent a bar in the graph, while each row would represent a power generation source.

3. RESULTS AND FUTURE RESEARCH

Despite the low price of solar energy, there is growing interest among large consumers in incorporating solar power generation into their operations. Many companies are recognizing the environmental and cost-saving benefits of investing in solar energy. However, there are still barriers to widespread adoption, including the need for significant upfront investment and the complexity of integrating solar power into existing energy infrastructure.

The Hungarian electricity system must adapt to accommodate the increasing demand for solar power generation. This includes updating infrastructure, revising regulations, and developing new mathematical models that accurately represent the complexities of integrating solar energy into the grid. Additionally, there is a need for greater collaboration between stakeholders, including energy companies, regulators, and consumers, to ensure a smooth transition to a more sustainable energy system.

As the demand for renewable energy sources continues to grow, it is imperative that the Hungarian electricity system evolves to meet these changing needs. By addressing the challenges associated with solar power generation, the system can become more resilient and sustainable in the long term. Ultimately, the interest of large consumers in solar power generation presents an opportunity for positive change in the Hungarian energy sector.

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