ISSN 1590-8844
International Journal of Mechanics and Control, Vol. 25, No. 01, 2024
https://doi.org/10.69076/jomac.2024.0014

ADVANCEMENTS IN WOOD PELLET PROCESSING AND ECONOMIC EVALUATION OF REPLACING OIL BOILERS

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ABSTRACT

In recent years, there has been a notable increase in the use of wood pellets as an energy source for residential heating, fulfilling both space heating and domestic water needs. Wood pellets represent an environmentally friendly fuel source with zero carbon emissions. Their use is considered sustainable, efficient, and reliable for households, commercial operations, and small-scale industrial processes. The objective of the paper is to analyze the economic feasibility of substitution oil boilers in schools and kindergartens in the city of Tirana, Albania with pellet boilers. This study aims to contribute valuable data and knowledge for the advancement of the wood pellet industry in the Korça region and its use in the gardens and schools of the city of Tirana. Using a combination of descriptive analysis and economic evaluation, the study reveals that the evolution of the wood pellet sector is efficient and economically favourable. Furthermore, wood pellet boiler presents a more economical and efficient alternative to traditional oil-based heating systems. The results showed that the replacement of boilers for kindergartens and schools in Tirana is a better choice with significant benefits in the cost of fuel.

Keywords: Wood pellets, economic analysis, energy, fuel consumption, boilers

1 INTRODUCTION

Recent developments have underscored the ongoing significance of energy concerns, both within Albania and globally, as a fundamental priority for socio-economic advancement. These concerns are prominently manifested in the call for sustainable development practices, ensuring the efficient utilization of energy resources at minimal expense and without environmental degradation. Wood pellet production plays a pivotal role in bolstering local economies, fostering the creation of high-quality jobs, and its expansion not only aligns with the attainment of the EU's 2050 carbon neutrality goal, but also fosters sustainable recovery efforts. During the transition from 2021 to 2022, the global pellet production experienced a significant increase, rising from 44.7 million tons to nearly 46 million tons [1].

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The year 2022 marked a distinctive landscape for the pellet market, characterized by exceptional demand dynamics. The early months of the year witnessed an unprecedented surge in demand, partly due to the lingering effects of the remarkable year that was 2021 [1].

In the EU27, pellet production exhibited a consistent upward trajectory, rising from 19.83 million tons to over 20.5 million tons [1]. Notably, Germany maintained its leading position, as the largest producer, contributing more than 3.5 million tons. The EU27's overall production highlights its substantial impact, in the global pellet market. The "Other Europe" region faced significant disruptions due to the ongoing conflict between Ukraine and Russia. These disruptions had substantial consequences, particularly for Russia, a key pellet producer known for its consistent growth. In recent years, the global consumption of pellets has shown a consistent upward trend, largely driven by significant environmental initiatives undertaken by various nations. Particularly noteworthy was the previous year, which marked a remarkable milestone with an unprecedented surge in consumption, surpassing 6 million tonnes and reflecting a substantial 16% increase [1]. Within the global landscape, the EU27 maintains its preeminent status as the largest consumer of pel-lets, accounting for over 24 million tonnes out of the 46 million consumed worldwide in 2022. This commanding figure, while substantial, does exhibit a slight decline of approximately 2% when juxta-posed with the record-breaking consumption levels of the preceding year, 2021. Wood pellets, a type of wood fuel, are usually made by compressing sawdust or finely ground woody materials. Due to the high compression of the raw materials, the pellets boast exceptional density and possess very low moisture content, typically below 10%. These two traits—high density and low moisture content—ensure that the pellets demonstrate remarkably high combustion efficiency [2]. Wood smoke harbors harmful pollutants like carbon monoxide and particulate matter, however, pellet boilers, can significantly reduce the emission of particulates from burning wood. Currently, approximately 80% of globally produced pellets are derived from woody biomass. In many cases, by-products from sawmills such as sawdust and shavings are utilized. Some large pellet mills also utilize low-value wood as raw material. In Europe, wood residues have been transformed into pellets for household heating since the 1970s [3]. Although biomass-based solid fuels haven't been as widely adopted as biomass-based liquid fuels like ethanol, which can directly substitute petroleum products, other studies have assessed the economic viability of pellet production. This has been accomplished through analyses of the manufacturing process in specific case studies [4], [5], or by comparing manufacturing systems across different countries [6]. Some studies, such as Tabata and Okuda, [7] and Nishiguchi and Tabata, [8], have examined the economic and environmental sustainability of pellet processing. Others, like Paolotti et al. [9], have conducted economic and environmental analyses of their transportation from production sites to consumer areas. The utilization of biomass as a fuel for heat and power production is becoming increasingly vital, driven by the imperative to reduce carbon dioxide emissions into the atmosphere [10]. Developing wood pellet products offers numerous advantages, including: (a) serving as an environmentally friendly fuel with zero carbon emissions, a recognition endorsed by the United Nations; (b) being utilized in power plants to mitigate CO2 gas emissions; (c) providing a relatively high-cost energy source that is environmentally friendly and sustainable for future generations; and (d) being suitable for the forestry sector [11]. Numerous studies have examined energy usage in educational facilities, worldwide. In Taiwan, for instance, the annual ratio of thermal energy consumption was observed [12]. In Cyprus, findings indicated that the energy intensity within educational buildings was 62.75 kWh/m2/year, with 38.59 kWh/m2/year allocated to thermal uses [13]. In Ireland, schools exhibited an average heat consumption of 53 kWh/m2/year [14]. The high energy efficiency of regional buildings relies on well-insulated building envelopes [15]. Among heating devices, pellet boilers stand out as alternatives to gas and oil boilers, based on renewable sources. Pellet boilers have the capability to fully meet heating and domestic hot water demands, or they can be integrated with additional technologies, such as solar collectors [16]. The analysis of new resources and related technologies, as well as the impact on the environment, with the aim of reducing it, are in the focus of research work in other countries, and in Albania. In this context, the power system of Albania has been investigated with the aim of improving it [17]. The impact of renewable energy for Albania, referring to the national energy balance for Albania [18], is given in the Table I.

Table I - Production and consumption of primary energies in Albania

Description	2021	2022
Consumption	1,984	2,010
– Lignite	187	118
– Crude oil	1,054	1,154
– Natural gas	7	6
– Electric power	573	567
– Fire wood	146	148
– Others	17	17

One of the features of primary energy consumption in Albania is the large-scale use of electricity for heating buildings. Taking into consideration this use of energy, as well as the need for diversification, efficient use and environmental protection, it is of interest to analyze the use of biomass for heating homes. Although the focus will be on the use of pellets, the analysis can also be used on other forms of wood used to produce heat. Compared to other biomass upgrading technologies, palletisation is a relatively efficient, straightforward, and cost-effective process [19-22]. The four key steps within this process include pre-milling of raw materials, drying, milling and densification of the product. These steps facilitate the production of a homogeneous fuel with low moisture content and high energy density. When dry raw materials are readily available, only milling and densification are necessary. Biomass stands as the primary heating energy source in the Western Balkan region. Particularly in rural locales, biomass serves as the primary heating source for the majority of the population. While the production of pellets and briquettes is on the rise, much of it is directed towards exports. Investment opportunities abound in the Western Balkans, where the benefits far outweigh the costs. Replacing inefficient boilers with efficient ones, switching from electric heating equipment to efficient biomass boilers, and switching from electric heating equipment to wood-burning heating boilers in high-rise buildings are all economically feasible options. Additionally, transitioning boilers from fossil fuels to biomass-based heating systems offers attractive economic prospects for the region. Furthermore, investments in efficient technologies result in numerous benefits, including cost savings, reduced consumption, decreased reliance on electricity, and lower levels of dust and greenhouse gas emissions. Of particular interest is the utilization of pellets in various buildings, particularly schools, and kindergarten, which is the focus of this article.

2 MATERIALS AND METHODS

2.1 PROJECT DETAILS

The replacement of oil boilers in most schools and kindergartens in Tirana with pellet boilers will be done with the pellets produced in the production factory in Korçë, (Albania). The Albanian wood pellet market boasts numerous advantages, including abundant raw material supply and convenient transportation infrastructure. The pellet will have a low moisture content of 8-10% and a low ash content respectively 0.5-0.8%. The investment was carried out using the waste of the wood processing factory in Maliq as well as the wood waste of the Korca region and consists of the construction of a factory for the production of pellets with a capacity of 2.5 tons / h and an annual production of approximately 12,000-13,000 tons of pellets / year.

Table II - Technical data of raw material and pellets

Type of Raw Material	50% Resin Wood (pine or spruce) + 50% Deciduous Wood
Dimensions of the Raw Material	Sawdust or Shavings 10x10x5mm Maximum
Humidity of the Raw Material at the Entrance of the Pressure Line	10-14% Maximum
Density of Raw Material at the Entrance of the Production Line	150-200 kg / m^3
Dimensions of the Raw Material at the Entrance of the Press	2-4 mm in fibrous form
Pellets	Φ 6 mm
Pellet Production	2.5 ton / hour

2.2 PELLET PRODUCTION PROCESS

To gain a comprehensive understanding and conduct an analysis of the factors influencing both the economy and environmental footprint, it is imperative to delve into the technological intricacies of a pellet production facility.

In the initial stages, raw materials derived from wood waste, sourced predominantly from wood processing factories, such as sawdust, shavings, and assorted wood remnants, are meticulously stored within the confines of the plant premises. Subsequently, these materials undergo a meticulously orchestrated process, beginning with their transition to a shredding and grinding line, comprising a sophisticated array of equipment, including conveyors, hammers, and shredders. Once subjected to this process, the materials are meticulously transformed into diminutive pieces measuring 3-5 cm, facilitating their seamless conveyance to a designated bunker. From there, they embark on a journey via a screw-type conveyor, ultimately finding themselves within the confines of a drying oven. Here, the material undergoes a meticulous drying process, harnessing the power of hot air to achieve optimal moisture content.

The requisite hot air essential for the drying phase is generated within boilers, leveraging fuel sourced from the waste produced during the initial treatment of raw materials. This innovative approach not only ensures efficient resource utilization but also eliminates the associated costs typically incurred during the drying process. To safeguard against the passage of sparks or heated shavings into the drying oven, a specialized spark and shaving extinguishing device is meticulously installed between the boiler and the oven, ensuring optimal safety standards are upheld throughout the operation. Upon completion of the drying cycle, the material emerges with a meticulously controlled moisture content of 14%, signifying readiness for subsequent processing stages.

The material earmarked for pellet production undergoes a meticulous journey, commencing with its induction by a fan and subsequent conveyance to the finest grinding mill. After grinding, a suction fan meticulously collects the material within a bunker before seamlessly transporting it to the pellet production presses, where it undergoes a transformative process, emerging as cylindrical pellets with a diameter of 6 mm. Demonstrating remarkable efficiency, the production capacity of this cutting-edge press machine stands at an impressive 2.5 tons per hour. As the freshly formed pellets exit the press, they bear a temperature of 85°C, necessitating a cooling phase to achieve ambient temperature prior to packaging. This essential cooling process is seamlessly executed through the utilization of an air cooler outfitted with a fan, ensuring optimal conditions for subsequent packaging procedures. In a meticulous endeavour to uphold the impeccable quality of the final product, the cooled pellets undergo a stringent screening process, where any damaged pellets incurred during the production are meticulously separated using a strainer. Following this meticulous quality assurance step, the pellets proceed seamlessly to the packaging machine, where they are meticulously packaged into 15 kg bags, ensuring convenience and efficiency for end-users.

Noteworthy for their superior quality, pellets produced from this state-of-the-art line boast, a meticulously controlled moisture content of 10%, ensuring optimal performance in various applications. Furthermore, they exhibit an impressive calorific value of 18,720, kJ/kg, equivalent to 5.2 kWh/kg, underscoring their efficacy as a high-performance energy source.

2.3 THE MAIN EQUIPMENT OF THE PELLET PRODUCTION LINE

The duration of the drying process hinges on variations in the quality of the raw material. As a result, rigorous monitoring of the raw material is essential to prevent significant fluctuations in moisture content and dimensions upon its introduction into the dryer. The dosing nourishing silo facilitates precise dispensing of sawdust onto the dryer feed belt. With a robust capacity of 2,000,000, Kcal/h, the hot air generator, equipped with an IN F 400 burner, incorporates an advanced automation and control system.

Operating seamlessly, the continuous rotary tubular dryer, model KT 2400, ensures consistent airflow, boasting a maximum drum diameter of 2.5m and a maximum drum length of 8.5m.

Table III - Drying Plant Technical Schedule

Raw Material	Sawdust or Wood Shavings
Dimensions	2-4 mm and/or 10x10x5 mm
Specific Weight of the Raw Material	> 300 kg/m^3
Fresh Product	Kg/h 5335 4640 4094
Humidity in the Entrance	% 45% 50% 55%
Humidity at the exit	% 12% 12% 12%
Thermal Power Installed	Kkal/h 2.000.000 2.000.000 2.000.000
H_2O Evaporation	Kg/h 2.000 2.000 2.000
Output Product (Dry Product)	Kg/h 3.335 2.640 2.094
Fuel (Dry Wood Sawdust)	Kg/h 500 500 500
Dry Product for Press	Kg/h 2.835 2.140 1.594

The dryer is an automatic vertical model Penta 3100 TC, equipped with the capability to pack products into bags.

Table IV - Technical data for the production and packaging of pellets

Product	Pellet
Dimension	Φ 6mm
The weight of the Bag	15kg
The Type of Bag	Pillow Bags
Movie Type	PE Polyethylene - Determined Based on the Weight of the Product and the Elasticity of the Material
The Size of the Bag	400x600 mm
Speed	3000 kg / hour
Charging System	Gravimetric Scales

3 CASE STUDY

Tirana is the capital of the Republic of Albania. The city of Tirana serves as Albania's largest urban center, encompassing key economic, administrative, political, industrial, media, academic, social, and cultural functions within the country. In Tirana, a subtropical-Mediterranean climate prevails with winter rainfall and average annual temperatures in July + 24° Celsius and in January + 7° Celsius.Tirana has 152 public schools and kindergartens, of which 82 schools and kindergartens use oil boilers for heating and domestic hot water, while in the other 70 educational facilities, oil boilers have been replaced with pellet boilers.

In these 70 educational facilities, 45 are schools and 25 are kindergartens. The power of oil and pellet boilers is determined based on the calculation of the heating load for the winter season, in the specific data of each building and taking into account the different losses in the building based on the relevant standard. The oil and pellet boilers used in educational facilities in Tirana are not from the same manufacturer and have different efficiencies. Pellet boilers have been installed in recent years during the reconstruction of educational facilities and the construction of new educational facilities. Each boiler features A steel housing encases a cast iron burner, which is operated by a mechanical feeding system. The design of the boiler gate ensures adequate access for inspection and cleaning while also maintaining insulation. Moreover, the feed hopper is adjustable, accommodating varying volumes, according to the boiler's power capacity. For the other 82 educational facilities, the option of replacing oil boilers with heat pumps, which have a high performance and are very suitable for the climatic conditions of Tirana, is being studied. Meeting the demand for hot water will primarily involve installing solart panels in conjunction with heat pumps. In our case study, the main advantages and disadvantages of the wood pellet processing industry usage and economic evaluation of replacing oil boilers in Tirana are listed below.

3.1 ADVANTAGES

- Wood pellets offer Tirana a renewable energy alternative, reducing reliance on finite fossil fuels and contributing to sustainability goals
- Switching to wood pellets from oil boilers can lead to long-term cost savings for consumers and businesses, as wood pellets often offer a more stable and affordable fuel option
- Wood pellets produce fewer carbon emissions compared to oil boilers, contributing to improved air quality and mitigating climate change impacts in Tirana
- By diversifying energy sources and reducing dependence on imported oil, Tirana can enhance its energy security and resilience to supply disruptions and price fluctuations in the global oil market
- Economic evaluation can assess the environmental benefits of transitioning to wood pellet heating, such as reduced carbon emissions and improved air quality, providing valuable insights for policymakers and stakeholders

3.2 DISADVANTAGES

- Wood pellet combustion can still contribute to local air pollution if not properly managed, potentially impacting air quality in urban areas like Tirana.
- Ensuring a consistent and sustainable supply of biomass feedstock for wood pellet production may pose logistical challenges, especially in regions with limited forestry resources
- Establishing the necessary infrastructure for wood pellet processing and distribution requires significant investment, which may pose financial barriers and require support from government or private investors

- Economic evaluation must consider behavioural and cultural factors that influence consumer preferences and adoption rates of wood pellet heating systems in Tirana, as well as potential resistance to change from traditional oil heating methods
- Switching to wood pellet heating systems requires upfront investment in equipment, infrastructure, and installation, which may be a barrier for some households and businesses in Tirana

4 RESULTS

The following table provides complete data for all educational facilities in Tirana (schools and kindergartens) in which pellet boilers are installed. The total energy demand [23-25] is estimated according to the respective methodology for heating and sanitary water, while the results of fuel consumption are given in Table VI. For economic analysis, current market prices 2024 are used. The two fuels under consideration have respectively the price of 185 lek / liter and 25 lek / kg.

Table V - The amount of oil and pellet supply in (kg) for the period November 15, 2023 - March 15, 2024.

EDUCATIONAL INSTITUTIONS			Hourly oil consumption (kg/hour)	Hourly pellet consumption (kg/hour)	The total amount of oil (kg) according to basic working hours	The total amount of pellets (kg) according to basic working hours
Nr.	Educational facility	Power (KW)				
1	School 1	390	20	59	7700	22715
2	School 2	175	13	29	5005	11165
3	kindergarten 1	90	7	17	2268	5508
4	kindergarten 2	104	7.5	18	2430	5832
5	kindergarten 3	170	13	29	4212	9396
6	School 3	465	21	76	8085	29260
7	School 4	450	20.2	71	7777	27335
8	School 5	465	21	76	4851	17556
9	School 6	465	21	75	8085	28875
10	School 7	465	21	75	8085	28875
11	School 8	355	18.5	60	4273.5	13860
12	School 9	465	21	75	4851	17325
13	kindergarten 4	90	7	16	2268	5184
14	kindergarten 5	104	7.5	17	2430	5508
15	School 10	465	21	76	4851	17556
16	kindergarten 6	104	7.5	18	2430	5832
17	kindergarten 7	66	6.3	12	2041.2	3888
18	kindergarten 8	110	8	17	2592	5508
19	School 11	500	21.7	81	5012.7	18711
20	School 12	500	21.7	80	5012.7	18480
21	School 13	474	20.5	75	4735.5	17325
22	kindergarten 9	104	7.5	18	2430	5832
23	kindergarten 10	104	7.5	18	2430	5832
24	kindergarten 11	66	6.3	13	2041.2	4212
25	School 14	314	17.5	36	4042.5	8316
26	School 15	359	18.7	60	4319.7	13860
27	School 16	465	21	75	4851	17325
28	School 17	465	21	76	4851	17556
29	School 18	523	22.3	76	5151.3	17556
30	School 19	698	37	100	8547	23100

31	kindergarten 12	130	10	25	3240	8100
32	kindergarten 13	66	6.3	12	2041.2	3888
33	kindergarten 14	130	10	23	3240	7452
34	School 20	345	18.5	60	7122.5	23100
35	School 21	349	18.8	61	4342.8	14091
36	kindergarten 15	104	7.5	18	2430	5832
37	kindergarten 16	60	6	12	1944	3888
38	School 22	372	19	42	4389	9702
39	School 23	372	19	42	4389	9702
40	School 24	450	20.2	72	4666.2	16632
41	School 25	200	15	34	3465	7854
42	kindergarten 17	66	6.3	13	2041.2	4212
43	kindergarten 18	120	8.5	21	2754	6804
44	School 26	465	21	76	4851	17556
45	School 27	320	17.8	45	4111.8	10395
46	School 28	698	37	100	8547	23100
47	School 29	465	21	75	8085	28875
48	School 30	500	21.7	81	5012.7	18711
49	kindergarten 19	104	7.5	18	1860	4464
50	School 31	465	21	78	4851	18018
51	School 32	295	17	40	3927	9240
52	School 33	295	17	46	3927	10626
53	School 34	395	20.3	65	3126.2	10010
54	School 35	500	21.7	80	5012.7	18480
55	kindergarten 20	104	7.5	18	2430	5832
56	kindergarten 21	66	6.3	13	2041.2	4212
57	kindergarten 22	50	5	12	1620	3888
58	kindergarten 23	90	7	16	2268	5184
59	kindergarten 24	62	6.1	12	1976.4	3888
60	School 36	100	7.3	18	1686.3	4158
61	kindergarten 25	50	5	10	1215	2430
62	School 37	300	17.2	40	3973.2	9240
63	School 38	160	10	29	2310	6699
64	School 39	145	9	25	2079	5775
65	School 40	233	15	35	3465	8085
66	School 41	400	20.4	70	4712.4	16170
67	School 42	174	13.1	29	3026.1	6699
68	School 43	350	18.7	60	4319.7	13860
69	School 44	372	19	42	4389	9702
70	School 45	255	16.4	36	3985.2	8748
	TOTAL				**282,532**	**834,585**

Table VI - The annual fuel consumption

Fuels	Unit	Consumption
Diesel	liters	282,532
Pellet	ton	834,585

Table VII - Comparison Pellet- Oil

Oil consumption: 282,532, liters/year x 185, lek / liter = 52,268,420, lek / year
Pellet consumption: 834,585, kg / year x 25, lek / kg = 20,864,625 lek/year
Savings: 52,268,420 - 20,864,625 = 31,403,795 lek / year = 311,236 EUR

5 IMPACT ON ENVIRONMENTAL PROTECTION

In this regard, the focus extends beyond merely economic interests in energy production to encompass considerations of air quality and environmental protection. This is particularly pertinent in the context of wood processing and pellet production waste, where combustion efficiency can reach as high as 99%. The utilization of biomass as a substitute for traditional fuels such as oil offers numerous benefits for environmental protection, notably through a significant reduction in CO_2 emissions released into the atmosphere.

When gas or oil are burned for heating, carbon extracted from underground sources is transferred into the atmosphere, contributing to the greenhouse effect. In contrast, biomass combustion does not add to the greenhouse effect since the carbon released from burning wood originates from the atmosphere itself. Additionally, biomass typically contains minimal sulfur content (0.01-0.1%), further reducing environmental impact.

Table VIII - The concentration of combustion gases

Composition	Border
Powders	<100 mg/m^3
Sulfuric anhydride	<14 mg/m^3
Nitric oxide (NOx)	<99 mg/m^3
Carbon monoxide	<99 mg/m^3
Organic composition	<150 mg/m^3
Chlorine - Fluorine	<6 mg/m^3

Nitrogen compounds, including NOx and N_2O, play crucial roles in human health. However, the concentration of nitrogen in pellets remains relatively low, typically ranging from 0.1% to 0.5%.

High combustion temperatures exceeding 1,000°C primarily influence the formation of nitrogen compounds, whereas in pellet heating boilers, temperatures typically range between 700°C and 800°C. With the advancement of pellet boiler technology, the production of carbon monoxide, resulting from incomplete fuel combustion has become negligible.

Chlorine compounds, such as hydrochloric acid, ammonium chloride, calcium chloride, and potassium, are present in minute quantities of around 0.5 mg/kg. The formation of these compounds is easily controllable, and their reduction depends on a variety of factors, including the physicochemical properties of the biomass utilized, the combustion equipment employed, and the degree of automation. Automatic adjustment of the air-to-fuel ratio for combustion, coupled with precise temperature control, significantly contributes to minimizing these pollutants. Minimalt sulfur and other pollutant content in biomass significantly reduces the likelihood of acid rain formation. Additionally, it's essential to recognize a fundamental distinction between CO_2 emissions from fossil fuels and those from biomass. As previously explained, biomass Combustion does not lead to an increase CO_2 levels.

Furthermore, while wood pellet processing offers a renewable heating option with established technology and availability, it's essential to consider its environmental impacts and limitations. Comparing it with other renewable energy options such as solar, geothermal, and wind power highlights the diverse range of sustainable heating solutions available, each with its own set of advantages and challenges [26-30].

The most suitable option will depend on factors such as geographic location, energy requirements, upfront investment, and environmental considerations.

6 CONCLUSIONS

The economic analysis of the replacement of the oil boilers with pellet boilers with reference to Albanian unit costs of energy showed that a considerable economic benefit is achieved. The use of technology that uses waste as fuel, ensures the production of pellets with moisture <10%, even <8.7%. The use of this waste also affects the protection of the environment. Based on the elemental composition of the pellets produced in this factory, the ash produced results in a small amount of 0.7% per year. From the point of view of environmental pollution, gas emissions meet the standards of the European Union in this field, both for CO, NOx and PM.

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