

Article

Economic Efficiency of Solar and Rainwater Systems—A Case Study

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Abstract: The study deals with the analysis of data from a selected tourism facility and the implementation of a solar system and a rainwater system, which are an alternative to commonly used energy sources. The objective is to evaluate the potential savings from the use of the solar system for water heating and the rainwater system for purposes other than potable use with respect to local conditions of sunlight and rainwater variability. The facility holds 257 beds allocated in 124 rooms on 5 floors. The result of the contribution is an economic evaluation of the efficiency of investments in the proposed systems and the resulting recommendations in the field of energy flows in the selected facility. Appropriate formulas including the consumption of hot water, the amount of energy needed to heat water, the cost of the consumed energy necessary for heating and the average annual rainfall in the location, water consumption for clearly identified purposes of alternation with rainwater, the initial investment costs and operating costs of the solar and rainwater systems, were used for an economic evaluation of the investment into the solar and rainwater systems. Based on the economic evaluation, the economic efficiency of the proposed systems and the return on investment was calculated. The payback periods for the solar system used for hot water heating and the rainwater system used for non-potable purposes, accepting the local conditions, are 7 and 15 years, respectively.

Keywords: solar energy; rainwater; alternative energy sources; economic efficiency



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1. Introduction

The issue of the use of renewable energy sources in the business sphere is an increasingly discussed topic in all spheres of the national economy in the current era of business greening [1,2]. Increasing the share of energy produced through renewable sources not only has a positive impact on environmental quality, but their introduction also creates space for supporting the development of the socio-economic area of the national economy [3,4]. The use of renewable resources, including water sources as a strategic raw material, is currently becoming the subject of greening to business activities [5,6]. For these reasons, it is necessary to define exactly the criteria and possibilities of supporting the introduction of pro-environmental technologies into business practice which fundamentally determines the environmental quality and its development in the primary, secondary and tertiary spheres [7,8]. For an effective business with the use of pro-environmental technologies, the fundamental determinant is, above all, the return on investment [9,10], regardless of the environmental quotient, while the fundamental determinant for mitigating the impacts of climate change is the use of renewable energy sources and water sources primarily representing the capture of rainfall in the place of their impact, or their further use in business activities. It is for these reasons that it is necessary to implement all available resources for the needs of greening business activity [11], which will interpret the interests of anthropogenic society in interaction with the development of environmental quality and the use of all available alternative sources of energy [12]. A responsible approach to the use of renewable energy sources, the use of ecologically appropriate technologies

and the introduction of the so-called green management is becoming an integral part of the activity of business entities whose intention is to stay on the market and continue to be a competitive enterprise [13–15]. The implementation of green management opens up space for many companies to become a company that tries to eliminate negative aspects of environmental quality and save in the areas of consumption of energy, raw materials and other inputs [16,17]. The presented study concentrates on the implementation of a solar system and a rainwater system in a tourism facility providing comprehensive tourism services in the East of Slovakia.

Solar systems are widely used in many countries around the world. Recently, growth in the use of solar systems was recorded in Poland. It is documented by the growing capacity of installed photovoltaic systems recorded by the Polish statistical office and the Polish power grid [18]. In New Zealand, solar hot water systems are promoted in an effort to reduce greenhouse gas emissions. These systems are not only financially attractive for consumers due to the average cost of electricity but also support local environmental and energy security [19]. Even some oil-rich countries try to make some efforts to implement renewable energy sources, but due to the low cost of non-renewable energy sources, the cost of the solar energy system is too high for business entities and households to invest in solar systems [20]. Nevertheless, in Brazil, the solar system is used to heat water in winter despite high initial costs that are balanced by the low cost of energy when using the solar system [21]. Solar energy is also used in agriculture in Vietnam [22], Uzbekistan [23] and Ukraine [24] and in self-powered Small Base Stations that are the constituents of next-generation cellular networks [25]. Solar systems are also used in combined systems for the production of both thermal and electrical energy [26]. The use of renewable energy sources of high efficiency to produce hot water, even in combination with the existing heating system, reduces expenses and improves the living standards in homes. It also helps to meet the European Union requirements and the national energy needs [27].

Many cities face water supply problems due to the growing population, municipal pipe leakage rates, etc. [28]. Using a rainwater system in any facility or household can significantly reduce drinking water expenses. This saving can be conducted by using rainwater in applications that do not require drinking water quality parameters, for example, flushing toilets, washing machines, and watering of gardens [29]. In urban areas use of rainwater systems is considered a practical means of rainwater harvesting with an additional water supply for non-potable use [30]. For the cost analysis (an analysis of potential savings), rainfall data, the roof area of the building, the water consumption per capita, the cost of the rainwater storage tank, and the number of residents should be considered [31]. The economic impact of the rainwater system can be positively affected by income, storage capacity, water price, age of rainwater harvesting, and total cost [32]. One of the requirements for the use of rainwater in different applications is also the removal of solids [33], which is usually provided for by the installed system and is not the subject of the presented study.

Based on these facts, the objective of this study was an evaluation of potential savings from the use of a solar system for water heating and a rainwater system for purposes other than potable use in the tourism facility with respect to local conditions, applicable laws, available sunlight and rainwater quality. The novelty of the article spreads in detailed analyses and quantification of points to the payback period of the investment to the use of a solar system and a rainwater system in the real conditions of a tourism facility in the Slovak Republic (SR).

2. Materials and Methods

The object of the study is the tourism facility providing comprehensive tourism services in the city of Košice, SK. The data and information necessary for the calculations and the subsequent design of the project were provided by the owner of the facility; therefore, the processing of the analytical part did not require additional data. The particular

name of the facility is not used as it is not necessary for the intended purpose of the study and possible generalization of the results.

There are 257 beds allocated in 124 rooms on 5 floors in this tourism facility. Various types of rooms are available, namely single, double, triple and quadruple rooms, including two separate suites. Since the facility also offers the possibility of longer-term accommodation and its capacity is relatively high, a pair of rooms by default share one toilet and bathroom with a bath or a shower (except for apartment rooms). In summary, the tourism facility has 63 shower facilities with the same number of toilets. There is also a laundry room with an automatic washing machine in the building, which is still sufficient for the needs of the accommodated guests. For the needs of greening the business activity and due to the availability of the necessary information, solar panels and rainwater use were analyzed in the tourism facility, which will also support the tourist facility in obtaining the European Ecolabel “The Flower” (https://ec.europa.eu/environment/archives/ecolabel/index_en.htm, accessed on 1 December 2022).

In the design of the solar system, the average daily occupancy of the facility, the consumption of hot water, the amount of energy needed to heat water and the cost of the consumed energy necessary for heating were quantified. These parameters determine the design of the solar system and the calculations of the costs associated with the procurement of the solar system. The annual heat demand for water heating (P_t) was calculated based on the equation [34]

$$P_t = T_v \times S_v \times V_p \times 365, \quad (1)$$

with

T_v —the need for the heating of 1 m³ of water = 5.85 m³ of gas,

S_v —water consumption (m³/day),

V_p —calorific value of gas (kWh/m³)

In the design of the rainwater system for its use, the average annual rainfall in the location, water consumption for clearly identified purposes of alternation with rainwater, which include flushing toilets, washing clothes in the laundry room and cleaning premises and other occasional uses, e.g., for watering, were determined. Subsequently, the amount of rainwater that can be collected from the roof and the need for water for defined purposes, which determine the design and calculation of the costs associated with the procurement of the rain system, were quantified. The volume of rainwater, in accordance with the Decree of the Ministry of the Interior of SR no. 397/2003 Coll., which establishes the details on the measurement of the amount of water supplied by the public water supply system and the amount of discharged water, on the method of calculating the amount of discharged wastewater and water from surface runoff, and on indicative water consumption figures, was calculated based on the equation

$$Q = H_z \times S \times \Psi \quad (2)$$

with

Q —the amount of water from the surface runoff discharged into the public sewer;

H_z —annual average from the long-term precipitation for the given location in (mm/year);

S —the size of the relevant area from which water from the surface drain drains into the public sewer (m²);

Ψ —runoff coefficient determined depending on the nature of the surface area.

The volume of the storage tank for the rain system (V_n) was counted based on the calculated need for rainwater according to the equation

$$V_n = Q_r \times DZ/365 \quad (3)$$

with

Q_r —annual need for water (L/year) depending on the used capacity of the tourism facility and the needs of the guests staying there;

DZ —expected supply time of the storage tank for specified needs (days).

Determining economic efficiency in the form of a payback period for an investment is a rather complex process, as it depends on several factors that must be considered. In contemporary practice, several methods for quantifying the payback period are used, which generally consist of static methods (do not take the time factor into account) and dynamic methods (take the time factor into account). For the purposes of quantifying the return on investment in the proposed ecological measures, the following equation was used [35]

$$NI = \sum[(Ni - Vi)/(1 + u)^i] \quad (4)$$

with

Ni—initial investment costs + operating costs of the system (EUR);

Vi—revenues or energy savings (considering changes in energy prices) from the use of the selected system (EUR);

u—expected development of interest rates in the future period;

i—number of years since the installation of the selected system.

3. Results

The occupancy rate of the accommodation capacity of the tourism facility is different in the months of the year, with the highest being at the level of 80%. It is for this reason that the average occupancy of the analyzed facility was quantified, that is, 110 guests/day. The consumption of hot water is at the level of 2000.75 m³/year, and the amount of gas used for heating water is 123,897.88 kWh, representing the costs in the amount of EUR 22,069.29. Based on the calculations, EUR 8734.80 is needed to heat the water that serves the guests. For the needs of a tourism facility with the aim of achieving savings on gas consumption, it is possible to place solar collectors on a flat roof, the slope of which is 16.7°; a total investment of EUR 37,679.38 will be required (Table 1).

Table 1. The total cost of the proposed solar system.

Component	Number	Unit Price	Total Price
Flat solar collector TS 500	32 pcs	EUR 491.76	EUR 15,736.32
Assembly set	1 pc	EUR 617.52	EUR 617.52
Support structure for a pair of collectors	16 pcs	EUR 189.49	EUR 3031.84
Accessories to the supporting structure	1 pc	EUR 285.92	EUR 285.92
Dilatation stopper	1 pc	EUR 34.80	EUR 34.80
Single-line pump unit Grundfos	1 pc	EUR 804.00	EUR 804.00
Two-line pump unit Regusol	1 pc	EUR 1266.00	EUR 1266.00
Expansion tank	1 pc	EUR 197.74	EUR 197.74
Stainless steel pipe DN 20 with insulation	20 m	EUR 14.95	EUR 299.00
Transitions, reduced nipples, double clasp	-	-	EUR 333.08
Nuts, gaskets, insulating tapes	-	-	EUR 272.80
Regulus R2BC 1000	3 pcs	EUR 2210.40	EUR 6631.20
Pressure sensor	1 pc	EUR 73.14	EUR 73.14
Temperature sensor with regulator	1 pc	EUR 158.10	EUR 158.10
Heat pump WP2S	1 pc	EUR 4450.00	EUR 4450.00
Ground collector	1 pc	EUR 177.60	EUR 177.60
Heat transfer fluid Thesol (240 l)	1 pc	EUR 943.92	EUR 943.92
Additional components and parts	-	-	EUR 150.00
SUM OF SYSTEM COMPONENTS TOTAL			EUR 35,462.98
-discount on the total value of the components (15%)			EUR 5319.48
SUM OF COMPONENTS, INCLUDING DISCOUNT			EUR 30,143.50
+ price of complete assembly and cartage of the solar system (25% of the price including discount)			EUR 7535.88
SOLAR SYSTEM TOTAL			EUR 37,679.38

The final calculation of the economic efficiency of the proposed solar system was based on the current price of natural gas of EUR 0.06412/kWh and the predicted increase in interest rates in the future—3%. Based on the calculations of the return on investment in terms of Equation (4) listed in Table 2, we could conclude that the investment in the

solar system appears to be relatively advantageous as, with the specified parameters, the investor will already return the funds after seven years. Costs related to maintenance are assumed after six years of EUR 943.92.

Table 2. An economic evaluation of the investment into the solar system.

Year	Costs, EUR	Revenues, EUR	Interest Rate, %	Return, EUR	Savings, EUR
0	−37,679.38	0.00	0	−37,679.38	−37,679.38
1	0	5240.88	0.03	5088.23	−32,591.15
2	0	5476.72	0.03	5162.33	−27,428.81
3	0	5723.17	0.03	5237.51	−22,191.30
4	0	5980.71	0.03	5313.79	−16,877.51
5	0	6249.85	0.03	5391.17	−11,486.34
6	0	6531.09	0.03	5469.69	−6016.65
7	−943.92	6824.99	0.03	5549.34	−467.31
8	0	7132.11	0.03	4885.02	4417.70
9	0	7453.06	0.03	5712.15	10,129.85
10	0	7788.45	0.03	5795.34	15,925.19

As to the rainwater system, the quantification of the predicted consumption of rainwater according to the purpose of its use was calculated, while guests use approximately 499,622 L/year for flushing the toilets, approximately 68,250 L/year for washing clothes in the laundry room and approximately 60,129 L/year for housekeeping (Table 3).

Table 3. A quantification of input data on rainwater consumption.

Months in a Year	Capacity	Water Consumption, L/day		
		Toilets	Laundry Room	Housekeeping
01–05	30%	925.2	130	111.6
06–08	80%	2467.8	325	296.1
09–12	30%	925.2	130	111.6
Summary calculations depending on the use of accommodation capacity, L/year				
01–05	30%	138,780	19,500	16,740
06–08	80%	222,102	29,250	26,649
09–12	30%	138,780	19,500	16,740
Predicted need for rainwater (Sum)		499,662	68,250	60,129

The usable area of the roof, from which it is possible to collect rainwater in the analyzed tourism facility, is 534.6 m². Because of the average annual rainfall in Košice, which is 624 mm, in accordance with the Decree of the Ministry of the Environment of SR no. 397/2003 Coll., the amount of rainwater that can be collected from the roof was quantified to be 373.74 m³/year. However, from the performed quantifications, depending on the use of the accommodation capacity by the guests, the aggregate need for water is at the level of 628.04 m³/year. This fact clearly shows that the analyzed facility can only replace about 60% of the predicted need with rainwater, approx. 254 m³ will have to continue to be taken from the relevant water company, which is the Východoslovenská vodárenská spoločnosť, Ltd. Based on the quantifications presented so far, an accumulation tank with a volume of 22.4 m³ is suitable for the procurement of the rain system and the efficient use of rainwater, while the total cost of procurement is EUR 10,535 (Table 4), while the annual costs related to maintenance are approximately EUR 49.

Table 4. Total costs of the proposed rain system.

Components	Price, EUR
Underground storage tank CARAT S—XXL	8300
Filter device (set)	260
Technical set for water refilling ECO PLUS	1190
Self-suction pump SPERONI RSM 50	300
inlet pipes and protective discharge valve	135
assembly work and cartage	350
Total costs	10,535

The final calculation of the economic efficiency of the proposed rain system was based on the current price of water—1.7933 EUR/m³ and the predicted increase in interest rates in the future—3%, as well as the expected increase in the prices of water by about 6.5%. Based on the calculations of the return on investment in terms of Equation (4), the invested funds in the rain system will be returned to the investor after 15 years (Table 5).

Table 5. An economic evaluation of the investment into the solar system.

Year	Costs, EUR	Revenues, EUR	Interest Rate, %	Return, EUR	Savings, EUR
0	−10,535	0.00	0	−10,535	−10,535
1	−49	587.52	0.03	522.84	−10,012.16
2	−49	625.71	0.03	543.6	−9468.56
3	−49	666.38	0.03	564.99	−8903.57
4	−49	709.70	0.03	587.02	−8316.55
5	−49	755.82	0.03	609.71	−7706.84
6	−49	804.95	0.03	633.1	−7073.74
7	−49	857.28	0.03	657.20	−6416.54
8	−49	913.00	0.03	682.05	−5734.49
9	−49	972.34	0.03	707.67	−5026.82
10	−49	1035.55	0.03	734.08	−4292.74
11	−49	1102.86	0.03	761.33	−3531.41
12	−49	1174.54	0.03	789.43	−2741.98
13	−49	1250.89	0.03	818.43	−1923.55
14	−49	1332.19	0.03	848.34	−1075.21
15	−49	1418.79	0.03	879.21	−196.00
16	−49	1511.01	0.03	911.08	715.08
17	−49	1609.22	0.03	943.96	1659.04

4. Discussion and Conclusions

SR is not one of the countries whose climate is characterized by significant length and intensity of sunlight [36,37]. Nevertheless, based on this fact and the existing potential, there are several ways to use the sun's energy actively. The possibilities of using solar energy are, of course, given the amount of sunlight falling on the Earth's surface [38,39]. SR is a relatively small country, so the differences between the values of solar radiation in its regions are not very significant, and it is evident that most of the energy from the sun can be captured in the southern parts of the country [40]. The overall difference between the coldest and warmest regions is only about 15%, while detailed data on the achieved values are provided in Figure 1.

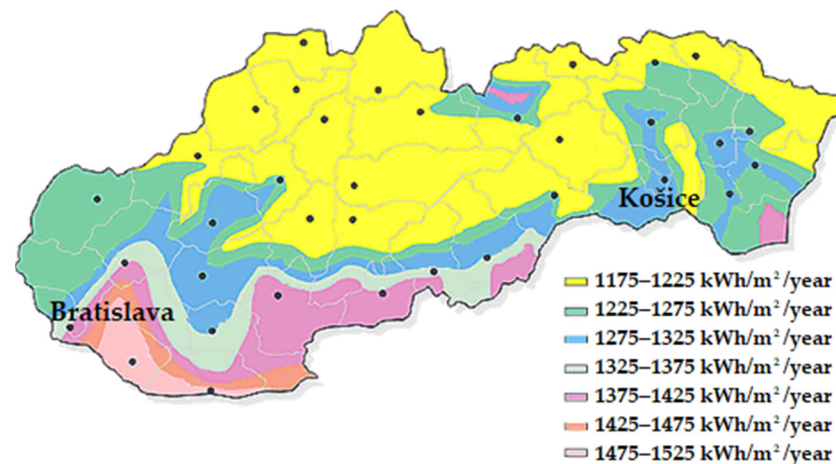


Figure 1. Solar map of SR with the intensity of sunlight [40].

SR, with its geographical location, thus represents an area for the use of solar energy, especially in the form of low-temperature systems [41]. From the view of the whole area, depending on the season, the values of captured solar energy are at the level of 850–1300 kWh/m²/year [40]. However, the data on the areal energy density of the total radiation from the sun is not the only significant data because the following climatic factors are also considered when designing the systems [42–46]:

- Theoretically possible amount of energy falling per day on the differently inclined and south-facing area;
- The mean intensity of solar radiation falling on various inclined south-facing flat surfaces;
- Average monthly relative lightness;
- Average monthly temperature in time of sunlight;
- Level of atmospheric pollution.

One of the most important indicators of investment in a solar system is the investment costs and the return on the invested costs. In Azerbaijan, the efficiency of using solar energy was also estimated based on its economic potential, as there is a potential to meet most of the energy needs of the country with solar energy. It was also reported that the main problems are the economic feasibility of solar energy and the necessary investment. The investment cost for a household was calculated at about EUR 500 [20]. If we consider one household for a family of three to four members, the cost of a solar system for a tourism facility of 257 beds would be about EUR 32,125 to EUR 42,833, which is comparable to the cost of a solar system in Slovakia. Another project of solar energy system combined with agricultural production was introduced in Central Vietnam at the cost of EUR 670,000 [22]. The system was designed with 2286 solar panels, which would mean about EUR 10,000 for 32 panels, which does not correspond to the costs of the solar system in Slovakia. This difference may be caused by the larger number of panels used in the solar system in Vietnam associated with a lower price (approx. EUR 100) per piece. An autonomous solar power plant was used in agriculture in Uzbekistan, but the use of solar panels may not be so profitable considering the high cost of installation and necessary repairs. In the study, only two solar panels were used with a total cost of about EUR 483, including installation and the price of only about EUR 65 per one piece of solar panel [23]. Considering 32 panels, the price would be about EUR 7700, which is much lower than the solar system in Slovakia. In a Polish study, it was reported that the invested capital is returned after about 12 years as an average of studied solar farms with a minimum of 8.5 years and a maximum of 13.5 years [18]. This does not correspond to the findings of this study that might be caused especially by the cost of used solar collectors and other equipment and material as well as other economic factors.

Climate change and severe weather changes, combined with high rainfall in a short period of time, are leading to the idea of protecting the environment from the floods and possible landslides that result from these climate changes [47,48]. It is especially for these that it is appropriate to address the issue of rainwater and its runoff, especially in areas where the annual total precipitation is high compared to the average measured values, and natural disasters can occur. Rainwater management, therefore, represents measures that eliminate undesirable negative effects on the environment and save water as a necessary resource for operation, and one of them is the accumulation and reuse of collected water in households and/or companies [48–52]. In addition, the system built in this way closes the water cycle, leading not only to ecological water management but also to its active use for several purposes [53,54].

The trend of a growing population is constantly leading to an increased demand for water—a vital natural resource [55,56]. For this reason, it is necessary to pay attention to the way drinking water is treated and to look for ways to use it efficiently so that it is preserved for future generations. One of the relatively modern ways to reduce the total consumption of drinking water in households as well as business units is to build a system for the collection and subsequent use of rainwater from surface runoff [57]. In the conditions of SR, this system is very little used due to the prices of drinking water and cheaper options for the construction of sewers that drain rainwater from buildings and the surrounding terrain. Higher costs of building a rainwater collection system, insufficient legislation and no financial support from the state are just other aspects affecting the minimum knowledge and interest in such technology. However, taking into account the ecological and construction–technical aspects of such a system as a whole, they can ultimately represent a concept that can also be used in the conditions of SR.

In India, the cost of a 7571 m³ accumulation tank installation for outdoor and indoor rainwater system use other than for drinking purposes is about EUR 1300 [30], which would represent a sum of about EUR 5500 in the case of a 22.4 m³ tank used in Košice. The cost of the Indian rainwater system is about 50% of the price of the Košice rainwater system. In a comparative economic efficiency study of two configurations of a rainwater system (gravity and pressure) in a commercial official building with a rooftop area of 1600 m² and with 560 persons in China, the total installation costs were about EUR 6000 for the pressure system and about EUR 4700 for the gravity system with a storage tank of 20 m³ [58]. The cost of this system is also almost 50% of the price of the Košice system. In Poland, the volume of the accumulation tank for the rainwater system strongly depends on the region due to annual rainfall. Nevertheless, the cost of the system is proportional to the tank's volume; thus, the cost of about EUR 4200 for a 10 m³ tank can be considered for comparison [59]. In this case, the cost of the rainwater system is comparable to the Košice system. The return on investment was counted for 7–19 years in the Polish study. It is a wide range but confirms that the cost return may take a longer time than in the presented study. In some areas, e.g., Iran, the return on investment is not appropriate as the installed rainwater system has no economic justification in spite of the use of low-cost materials [60].

The study points to the use of a solar system and a rainwater system in the real conditions of a tourism facility. The detailed analysis and quantification of point to the payback period of the investment showed the following:

- The solar system used for hot water heating with an average guest occupancy of 110 guests/day, accepting the use of the accommodation capacity during three months of the year at 80%, is after seven years;
- The rainwater system, which can replace only approx. 60% of the average water consumption by guests due to the area of the roof from which rainwater can be collected, the return on investment is only after 15 years;
- The investment cost and the return on investment may vary in different countries, but they are similar in EU countries for both the solar and rainwater systems, based on available studies.

The return on the investment in the use of a rainwater system is double the time of the return on the investment in the use of a solar system. This fact is limited by the area of the roof, from which it is possible to collect rainwater, for the needs of the investigated company, which has 124 rooms (257 beds) on 5 floors, which directly determines the overall usefulness of this ecological measure. It is for these reasons that it would be possible to reduce the payback period of the rainwater system by expanding the catchment area, e.g., completing the roofing of some exterior areas (summer terrace, parking areas). Despite this fact, both the proposed ecological measures may significantly contribute to the greening of the business of the analyzed tourism facility. Further study should aim at the investigation of replacing other possible sources in the tourism facility with alternative energy sources.

The presented study results are based on the data provided by the owner of the tourism facility. Thus, the limitations of the presented study may be the data on the average daily occupancy of the facility and the consumption of hot water, the amount of energy to heat water, the cost of the consumed energy necessary for heating that might unevenly change due to actual worldwide and local situation. As seen recently, due to SARS-CoV-2 pandemic restrictions, inflation, etc., the willingness of potential customers to use the services of the facility might significantly change. Moreover, the limitations of the study may be the data on the average annual rainfall in the location that might also unevenly change due to global warming and significant shifts in temperature.

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