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Original Research Article

Biomass and solar energy in buildings, energetic dark greenhouse, an economic approach analysis

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ABSTRACT

The use of different energy sources and the worry of running out of some of them in the modern world have made factors such as environmental pollution and even energy sustainability vital. Vital resources for humanity include water, environment, food, and energy. As a result, building strong trust in these resources is crucial because of their interconnected nature. Sustainability in security of energy, water and food, generally decreases costs and improves durability. This study introduces and describes the components of a system named "Desktop Energetic Dark Greenhouse" in the context of the quadruple nexus of water, environment, food, and energy in urban life. This solution can concurrently serve to strengthen the sustainable security of water, environment, food, and energy. For home productivity, a small-scale version of this project was completed. The costs and revenues for this system have been determined after conducting an economic study from the viewpoints of the investor and the average household. The findings indicate that the capital return period is around five years from the investor's perspective. The capital return on investment for this system is less than 4 years from the standpoint of the households. According to the estimates, this system annually supplies about 20 kg of vegetables or herbs, which means about one third of the annual needs of a family.

Keywords: Mini Energetic Dark Greenhouse; Food and Energy Nexus; Water and Environment Nexus; Sustainable Food Security

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1. Introduction

Water, environment, food, and energy are four vital resources for humans and provide the quality of human life[1]. The global demand for these resources is increasing due to population growth, urbanization and climate change, and it is expected that we will see a 50% growth compared to 2015[2]. Also, due to human society's reliance on basic resources, food, energy and water are expected to increase to 35%, 50% and 40% by 2030, respectively[3]. The issues that human civilizations face, including decreased food security, a lack of clean water, pollution, and the depletion of fossil fuel supplies, have caught the attention of numerous governments and research organizations[4]. Consequently, understanding the complex relationships between resources, the availability of water, food, and energy will have a significant impact on future sustainable development in all countries and regions[5]. Intrinsic and intertwined relationship between three sources of water and food and energy is known as "correlation". This correlation truly indicates how each resource is constrained in order to restrict use of other resources[4].

Due to the richness of the correlation concept, it cannot be interpreted from a single point of view. In order to better understand this notion, it has been examined from three complementary angles: analytical approach, management tool, and new order[6]. In order to decrease unexpected exchanges and enhance sustainable growth, the integrated management of all three sectors and inter-sectoral coordination are discussed. According to this opinion, this method is different from the common decision-making methods that consider individual criteria before solving each problem[7]. Due to the four-fold correlation between water, environment, food, and energy as well as the worldwide difficulties in the areas of energy, climate change, and food security, water energy food and environment nexus (WEFEN) has developed a solution known as the "Desktop Energetic Dark Greenhouse". In the present research, this solution has been studied for the city of Tehran.

Tehran is the most populous city and the capital of Iran. The population of this city has reached 8,679,950 according to the statistics of 2018[8]. Every Iranian household consumes a lot of vegetables and herbs annually. Most of these agricultural products are supplied from outside the city of Tehran and outside the province[9]. Because water resources, energy, environment and food have a two-way and reciprocal relationship, increasing the need for managing these challenges is a must. One of the suggested solutions to solve these challenges at the same time is the local production of some agricultural products by the consumer himself. Tabletop dark greenhouse is a system that can be used to provide part of the agricultural product needed by the urban consumer[10]. Due to the use of artificial light, this product can be placed even in environments without sufficient light, such as apartments. This product is very similar to the dark and closed greenhouses being developed in countries like Japan and America, but the main difference is that it is used in very small dimensions and in small residential scales.

In this research, a table-top energetic dark greenhouse is introduced and its various components are described. Finally, the economic analysis is performed to determine the costs and revenues for this system.

1.1 Research background

The table-top energetic dark greenhouse is a solution for providing sustainable food security, within the framework of the four-fold correlation of water, environment, food and energy. For this reason, first, the background of the correlation issue is stated, and then, the background of dark greenhouses in industrial and domestic dimensions is presented.

The world population will increase from the current 7.5 billion to 9.772 billion by 2050[11]. The demand for the provision of three fundamental human rights, namely security in sustainable energy, security in sustainable water, and security in sustainable food, has significantly increased in recent years due to the increase in population and improvement in quality of life[12]. On the other hand, this upward trend without an expert view has made the planet face an environmental crisis. Thorough the Fifth Assessment Report of the United Nations intergovernmental group, which was released in 2014 and was titled "The Challenge of Climate Change", acknowledged this challenge after years of research[13]. In the past years, in order to achieve the goals of sustainable development, the concept of solidarity attitude has been expanded and this attitude has been introduced as the only way of integrated and dynamic management for sustainable development[14]. The Latin word (NEXUS) means the act of tying and joining together, in such a way that it is not possible to open a knot alone. The United Nations University's food and energy correlation program popularized this phrase in 1983[15]. Before that, this word was used in medical, economic and political literature[16]. But since the 1970s, the view of "life cycle analysis" under the title "warehouse life cycle" has flourished among industrial owners. This view was proposed at the World Energy Conference in 1963. The warehouse's life cycle describes how much energy and raw materials are used to generate one industrial product unit. Finally, the "life cycle assessment" approach in the ISO 14000 standard was added as an index method for contrasting processes as the solid waste challenge grew in importance in the 1990s[17]. The World Economic Forum introduced "the notion of nexus" in 2011 to highlight the mutually dependent relationships between resource consumption and ensuring the security of food, water, and energy[18]. This gathering stated that the collaborative approach can improve sustainable water, energy and food security and at the same time support the transition to a green economy[19]. The global economy changed the correlation framework in 2011 to guarantee lasting security (water-energy-food). The intergovernmental UN delegation's 2015 report identified cooperation as the only strategy for achieving the program's 17 objectives for sustainable development. In the past years, many studies have been done on different systems in the context of correlation. According to the analysis of the Scopus article bank, the trend of these researches has greatly increased since 2015[16].

1.2 Dark greenhouse

Today, plant production units have been developed for the development of local production and fresh and high-quality products in urban areas[20]. These kinds of greenhouses have numerous benefits, including the ability to build in areas with limited light, maximize the use of land (layer cultivation), produce crops outside of the growing season, increase production per unit area, produce more than one crop annually, improve product quality (by managing environmental conditions and preventing pests and diseases), and reduce water consumption[21–23]. This type of plant production units in some countries such as Japan and America are in the research and development phase[24].

In addition to these industrial plant production units, some city dwellers in nations and regions like Japan, Taiwan, China, and certain Asian countries that do not have access to these sorts of units have begun generating some plant products in their living and working environments by using small, dark greenhouses at home. These types of greenhouses are suitable for home use, schools, hospitals and offices due to their small size[25]. An image of the use of these greenhouses in different environments is shown in **Figure 1**.

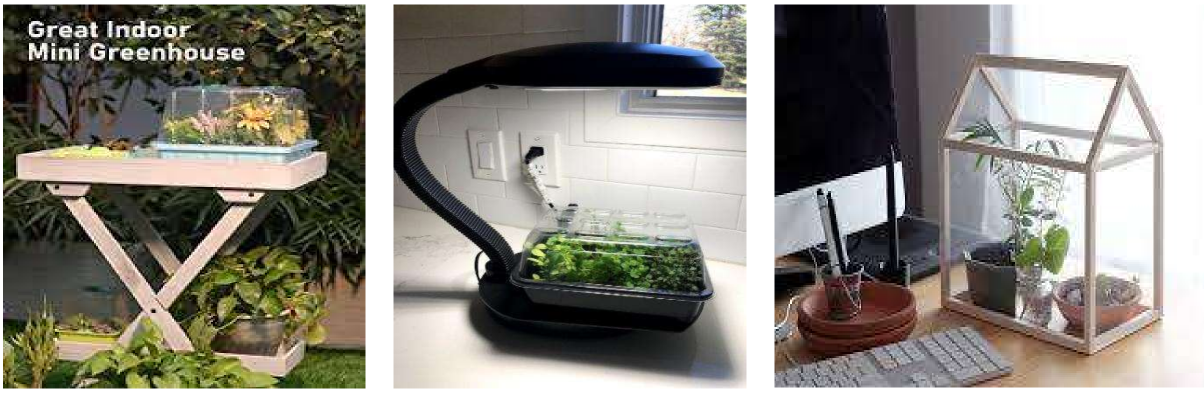

Figure 1. Application of small greenhouses with artificial light in restaurants, hospitals and schools[24].

Water basin: In 1996, Dr. John Anthony Allen invented and introduced the term "virtual water". Virtual water is the amount of water used to produce one unit of a product[26]. One method of reducing virtual water c is the employment of modern greenhouses, particularly dark domestic greenhouses given the minimal water consumption for the creation of each product unit. Large volumes of water are used during the cultivation phase to create each kilogram of various products, according to data on water use in traditional agriculture. A nutrient solution with minerals that is purchased yearly is used to irrigate the product in the tabletop, dark greenhouse. As a result, the consumer does not need to use urban purified water for this system, and in this way, water consumption has been saved.

Energy field: There is a concept of virtual energy that is related to the idea of virtual water that was stated in the previous section. The quantity of energy required to create one unit of a product is referred to as virtual energy. Due to the vast number of crops that are harvested in conventional agriculture, a lot of energy is used by equipment and machinery during the several stages of agriculture, such as land preparation, planting, sowing, and harvesting. Even after the harvest stage, a lot of energy is expended on moving the items into cold storage and keeping them there. In the field of energy, in addition to the amount of energy consumption, the cost of energy is also one of the challenges, so that sometimes because of this cost, the cultivation of some types of products is not economical. The entire yearly energy need for the desktop dark greenhouse is 146 kilowatt hours, which is related to the lighting and control system. As a result of this system, a significant amount of energy is saved.

Environment field: According to the correlation theory that was covered in the introductory section, four factors—water, environment, food, and energy—are correlated with one another and in both directions. As a result, reducing water and energy use has an effect on the environment as well. Less need for traditional agriculture will reduce the use of water and energy resources. An example of the impact of energy consumption on the environment is air pollution. The use of the table-top energy dark greenhouse reduces the need to transport food from the outside into the city and, as a result, causes less fuel consumption and less pollution in the air. The table-top energetic dark greenhouse produces high-quality goods with very little waste because of the carefully controlled environmental conditions. As a result, it reduces the amount of garbage that is created and has an impact on the field of urban waste management.

2. Materials and methods

2.1 System description

The desktop dark greenhouse is a semi-closed system with artificial light and controlled environmental conditions for plant growth. **Figure 2** shows a picture of three types of dark tabletop greenhouses in the Energy Conversion Laboratory of Amirkabir University of Technology. This system consists of a framework, plant-growing LED lights, sensors for measuring temperature, humidity, and light intensity, as well as a growth control unit.

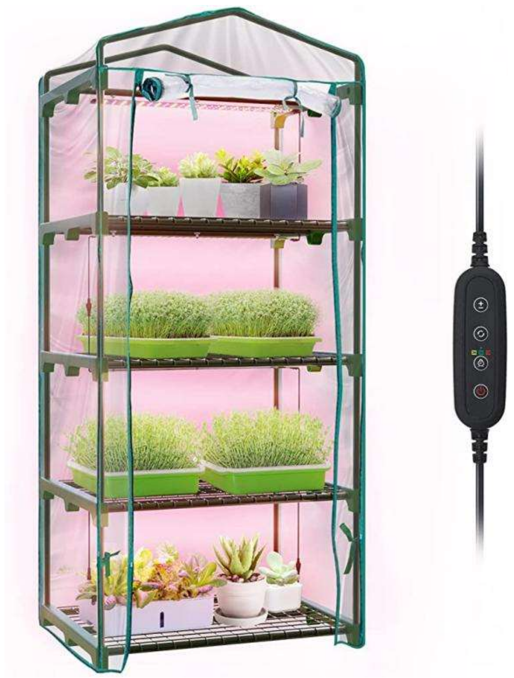

Figure 2. A picture of dark energy tabletop greenhouse.

Structure: The structure used can be made of different materials, the structure used in the tabletop dark greenhouses is made of MDF, PVC and double-layer tarpaulin.

LED lights for plant growth: LED lights are used as supplemental light due to the high efficiency of LED lamps, low heat generation and variety of light spectrum.

Sensors: The used sensors include temperature, humidity and light intensity sensors. These sensors send data to the growth control unit.

Growth control unit: It is used to process and manage environmental conditions.

Cultivation substrate: The plant is cultivated in this system by hydroponic method and its substrate is a combination of cocopeat, perlite and peat moss. This combination is used because it is light and maintains the moisture of the roots. This composition does not have the minerals needed by the plant. Therefore, minerals are available to the plant in the form of water solution.

Nutrient solution: The used nutrient solution is a modified example of Hoagland's solution, which was made by the energy systems engineering laboratory of Tehran University. This solution contains all kinds of mineral salts needed by a plant. According to the designed formulas of Hoagland solution, these salts are dissolved in water with a certain percentage.

2.2 Research methodology

An economic analysis of this study's findings was conducted from the perspectives of the consumer, or the households in Tehran, and the investment made to produce this product. In the economic analysis from the investor's point of view, the investment cost, working capital and production cost per year have been calculated. After that, the revenue generated by the sale of this system and food solution was determined. According to the costs and revenue in each year, the analysis of the profit or loss from producing this product in quantities of 4,000 units has been done. The time of return on investment and cumulative profit have also been computed.

In the second part, an economic analysis has been done from the perspective of the household in Tehran. The fixed investment cost (the price of an apartment tabletop greenhouse), the annual fixed cost (which includes the price of nutrient solution and the price of electricity consumed by the system), and the annual savings (the total cost of cherry tomatoes produced in one year) have all been calculated in the economic analysis of the second part. Then, by calculating the difference in costs and annual savings, the profit and loss earned from this product for the family and the investment return period have been obtained.

Introduction of the studied area: Tehran, the capital of Iran is used as the case study of this research. **Table 1** lists the units of Tehran city, including its population, the number of homes, the daily average of the products given, and the number of fruits and vegetables that Tehran households needed to consume annually in 2017. These statistics were extracted from the website of the Urban Statistics and Observation Center, from the subcategories of the Information and Communication Technology Organization of Tehran Municipality[27].

Table 1. The studied characteristics of Tehran city

Description	Amount
The population of Tehran city	8,679,950
The number of households in Tehran	2,907,240
Average daily product supplied	3,302 tons
Annual fruit and vegetable consumption of a Tehrani family	About 76 kg of fruits About 71 kg of vegetables and herbs

3. Results and discussion

This section examines the economics of a tabletop dark greenhouse, the components of which were explained in the section before, from the viewpoints of an investor and a home in Tehran.

3.1 From the investor's point of view

The cost of building and setting up the production line of the table-top energetic dark greenhouse system, which plans to produce 4,000 units of this product and 4,500 cc nutrient solutions, has been calculated.

Fixed investment: This cost includes the cost of purchasing equipment and the cost of preparation. The total of these costs is presented in **Table 2**. The cost of purchasing equipment includes the purchase of machinery and equipment (industrial sewing machine, electric tarpaulin cutting machine, pipe cutting and bending machine, wood laser cutting machine, assembly table, soldering table, electronic parts and soldering equipment) auxiliary equipment, transportation equipment and possible costs.

Preparation costs also include landscaping and land improvement, civil works, building and

Table 2. Startup costs (investment)

Cost description	Total cost (thousand $)
The cost of purchasing equipment	83.33
Preparation cost	800
Total	883.33

construction, pre-investment studies and other similar things for building a greenhouse. These costs are presented in **Table 3**. The costs associated with design, consultation, licensing, contracts, workshop placement, as well as the cost of valuing the product's patent and the cost of training human resources, are included in the pre-operational expenses in **Table 3**. Along with the main building, land preparation, guards, fence, and street construction are all included in the costs of civil construction. According to **Tables 2** and **3** and according to the explanations provided, the total start-up cost (investment) is equal 883,333 dollars.

Table 3. Preparation costs

Description	Cost (thousand $)
Costs before operation	511.90
Civil construction costs	261.90
The cost of electricity connection	10.71
The cost of office equipment	15.48
Total	800

Current expenses (working capital): According to the estimated costs in 2022, the amount of working capital (current) is estimated according to **Table 4**. The cost of employees' salaries includes 12 months' salary plus 3 months' holiday and bonus and annual leave and 1 month's annual leave. **Table 5** provides the investment expenses for establishing the energetic dark greenhouse production line.

Production cost per year: The production cost per year is also according to **Table 6**.

Table 4. Working capital

Description	Annual cost (thousand $)	Cost of circulation for 3 months (thousand $)
The cost of employee salaries	366.67	91.67
Repair and maintenance	7.14	1.79
The cost of energy and water consumption	1.43	0.36
Accident insurance	4.76	1.19
5% equipment consumption	4.17	1.07
2% building consumption	7.14	1.79
Other	1.55	0.48
Total	392.86	98.33

Table 5. Investment costs for setting up the energetic dark greenhouse production line

Description	Total investment (thousand $)
Fixed cost	883.33
3 months of working capital	98.33
Total	981.67

Table 6. The total cost of production per year

Description	Total annual cost (thousand $)	Cost of 3 months (thousand $)
Manpower	366.67	91.67
The cost of raw materials and packaging	1,333.33	333.33
Energy cost (water, electricity and fuel)	1.43	0.36
The cost of repairs and maintenance	7.14	1.79
Unforeseen	8.10	2.14
Total	1,716.66	429.29

Annual production revenue: The cost of the production product, which comprises the desktop energetic dark greenhouse and food solution, is shown in **Table 7** to help determine the annual income. Part of the starting capital of this production line (about 40%) has been provided through bank facilities. **Table 8** shows the income, costs, and annual gross profit resulting from receiving 1,023.81 thousand dollars of bank facilities with 15% interest, a 12-month grace period, a 24-month start-up period, a 5-year repayment period, and an inflation rate of 20%. In this table, it is considered that the annual production income and the annual production cost have increased by 20% in each year compared to the previous year.

When taking into account the payback of the facilities that were provided, **Table 8** indicates that the investment return period for installing this production line is 5 years. The cumulative wealth created for the investor after 9 years is equal to 6,130,952 $. The mentioned amounts are stated for starting the production line for the production of 4,000 samples of tabletop energetic dark greenhouse. If it is built for all the households of Tehran, i.e., 2,907,240, it will be much more profitable from an economic point of view.

Table 7. The price and gross income of the sale of table-top energetic dark greenhouse and food solution

Product name	The unit	Number	Sales unit ($)	Annual gross income (thousand $)
Tarpaulin greenhouse	Number	2,000	500	1,000
MDF or PVC greenhouse	Number	2,000	535.71	1,071.43
Food solution 500 cc	Number	4,000	11.90	119.05
-	Total	-	-	2,119.05

Table 8. Economic analysis data of energetic dark greenhouse from the investor's point of view

Description	Thousand dollars								
	First year	Second year	Third year	Fourth year	Fifth year	Sixth year	Seventh year	Eighth year	Ninth year
Annual production revenue	2,119	2,543	3,050	3,660	4,390	5,269	6,321	7,586	9,102
Fixed investment	883	71	0	71	0	214	0	476	143
Annual production cost	1,714	2,057	2,469	2,962	3,569	4,267	5,119	6,143	7,371
Facilities received	1,024	0	0	0	0	0	0	0	0
Annual installments of the facility	0	0	0	283	283	283	283	283	0
Annual gross special profit (loss)	405	486	581	343	531	505	919	683	1,588
Cumulative gross special profit (loss)	545	960	1,540	1,883	2,436	2,940	3,860	4,543	6,131

3.2 From the perspective of the family

For an urban household in Tehran, the initial investment cost includes the cost of purchasing a desktop dark greenhouse system. Also, the annual fixed cost is related to the annual purchase of food solutions and the cost of electricity consumed by the system in one year. Annual income is also the price of the total product produced in the year. The product produced in this economic analysis is cherry tomatoes, and the amount of production of this product in one year is assumed to be 20 kg. Of course, since the family does not sell the produced product, the term economic saving is a more appropriate word compared to income. The number of plantings per year, the total weight of the finished products produced during each cultivation period, and the cost of each weight unit of the product are multiplied to determine the amount of annual economic savings. The values of initial investment cost, annual fixed cost, annual economic savings, and calculated profit and loss are presented in **Table 9**.

Table 9. The economic analysis data of the energetic dark greenhouse from the perspective of a household in Tehran

Description	Thousand dollars				
	First year	Second year	Third year	Fourth year	Fifth year
Initial investment	500	0	0	0	0
Annual fixed cost	0.05	0.05	0.05	0.05	0.05
Annual economic savings	0.12	0.19	285.71	380.95	476.19
Annual gross special profit (loss)	−102.50	0.14	0.24	331.43	426.67
Cumulative gross special profit (loss)	−430.48	−289.52	−0.05	278.10	704.76

According to **Table 9**, in the first year, the cost is more than the economic savings. But from the fourth year onwards, the amount of annual savings has caused the economic benefit of this system for the family. Therefore, the investment return period is less than the fourth year. In the fifth year, this system has created a cumulative wealth of 705 $ for the family, which is less than the initial purchase price. According to the estimates, this system annually supplies about 20 kg of vegetables or herbs, which means about one third of the annual needs of a family. The complete demand of a family will therefore be met throughout the year, in addition to the economic cost, if more of this system is installed in a residential home or if it is made in a greater size in future designs.

4. Conclusion

In the present study, a table-top energetic dark greenhouse was introduced and its various components were described. The economic analysis performed on this product showed that from the investor's point of view, this system has a 5-year return period. Its accumulated wealth after 9 years and after the full payment of the installments of bank facilities is equal to 6,130,952 $. From the perspective of Tehrani households, this system has a return on investment of fewer than 4 years, and the household's total wealth after 5 years is 705 $. In addition to the economic benefits, this system reduces water and energy consumption and preserves the environment, which was mentioned in the concept of correlation, and also reduces air pollution and waste produced in the city. Therefore, it is anticipated that a desktop energetic dark greenhouse system will soon be installed in every residential unit together with other home appliances as a result of the development and marketing of this product.

From the economic sustainability perspective, energetic dark greenhouse release time resources for other purposes, especially because people do not need to travel long distances to obtain food. Thus, with more efficient and reliable water and energy solutions, people can do other activities more efficiently, keep their shops open longer, farm more efficiently and have more time for household chores and leisure.

Author contributions

Conceptualization, RZ and MANS; methodology, ZR; software, ZR; validation, MK, RZ and SM; formal analysis, MANS; investigation, ZR; resources, MK; data curation, SM; writing—original draft preparation, MANS; writing—review and editing, ZR; visualization, MK; supervision, RZ; project administration, SM.

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Conflict of interest

The authors declare no conflict of interest.

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