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Review

Program Design for an Integrated Air-Film System to Cope with Extreme Climate Demands for Water, Energy, and Food

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Abstract

With the increasing frequency of extreme weather events, the demand for water, energy, and food will continue to rise. However, after analyzing the current literature on water, energy, and food collection systems, respectively, it can be found that current resource collection systems don't have the ability to respond to extreme weather. Even if current resource collection systems are expanded or the number of existing resource collection systems increases, such passive resource-collecting systems will struggle to cope with resource demands in extreme weather. Nevertheless, an integrated system utilizing air film as the primary structural component devised in this paper not only offers the potential to collect rainwater, renewable energy, and food, but also significantly enhances the yield of resources through a symbiotic relationship between them. With the characteristics of air film, the integrated system is designed with functions of mobility, expansion and contraction, transmission, technological compatibility, and environmental friendliness. The above functions make the integrated system able to integrate rainwater, renewable energy, and food production systems into a single system. From the discussion, it is evident that the new functionality enhances the flexibility of resource collection within the integrated system, facilitates the compatibility of disparate resource collection techniques, and fosters the sustainability of resources through mutual support. It can be concluded that the designed integrated system is capable of meeting the demand for water, energy, and food in extreme weather. The flexibility of the integrated system is such that passive resource collection can be changed to active search and acquisition of resources. The mutual support among rainwater, renewable energy, food, and recycling of wastes serves to strengthen the adaptive capacity of the integrated system to the changing environment, which is of great significance for socioeconomic sustenance in extreme weather.

Keywords: air film, extreme weather, integrated system

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Introduction

The occurrence of extreme weather events has resulted in a number of significant disasters in the modern era. In the summer of 2022, Spain, France, the United Kingdom, Slovenia, Italy, Portugal, and other European nations experienced temperatures exceeding 40 degrees Celsius [1]. These conditions contributed to the ignition and spread of extensive wildfires across Europe, North America, and Asia [2]. Research shows that extreme heat, drought, and moisture are happening more often together, which is reducing crop yields in important farming areas around the world [3]. The occurrence of disasters caused by climate change and extreme weather events has a deleterious effect on the production of crops and livestock [4].

The overarching objective is to enhance the capacity to generate food, energy, and water. The research on extreme climate phenomena, such as severe droughts and floods, indicates that such events may persist for an extended period in the future [5]. It is of the utmost importance to ensure the continued scientific and economic stability of the nation during an extended period of extreme weather. This will necessitate the acquisition of a significant quantity of basic resources, including water, energy, and food. If the aforementioned essential resources are not available in the future, many nations and areas will face long-term challenges as long as the world's harsh climate persists [6].

The present water-energy-food nexus study posits that meeting the demand for food production through the optimization of water and energy resources is a crucial step in addressing the challenges posed by population growth and economic development [7]. In order to optimize the efficiency of resource allocation, it is imperative to develop models that can simulate the impacts of varying water and energy ratios on food production and consumption [8]. Long-term research on population and the economy within the framework of water-food-energy resources has revealed that water resource management is of fundamental importance [9]. The availability of water resources is a critical factor in food production and hydro-power generation; energy can also be employed to facilitate desalination, wastewater recycling, and fertilizer production [10]. Livestock biomass in the production process of the food system represents a promising sustainable bio-energy source [11]. In conclusion, scholars have posited that there is a symbiotic relationship between water harvesting systems, energy harvesting systems, and food production systems, wherein each system is dependent on and supportive of the others [8].

Material and Methodology

Material Selection

The technology of air film construction is continuing to mature, with an expanding range of applications [12]. Additionally, air film construction displays a number of characteristics that render it an appealing option, including mobility, a suitable economy, a brief construction period, and robust malleability [13-16]. It would be prudent to consider the design of a multi-functional integrated system utilizing air film as the

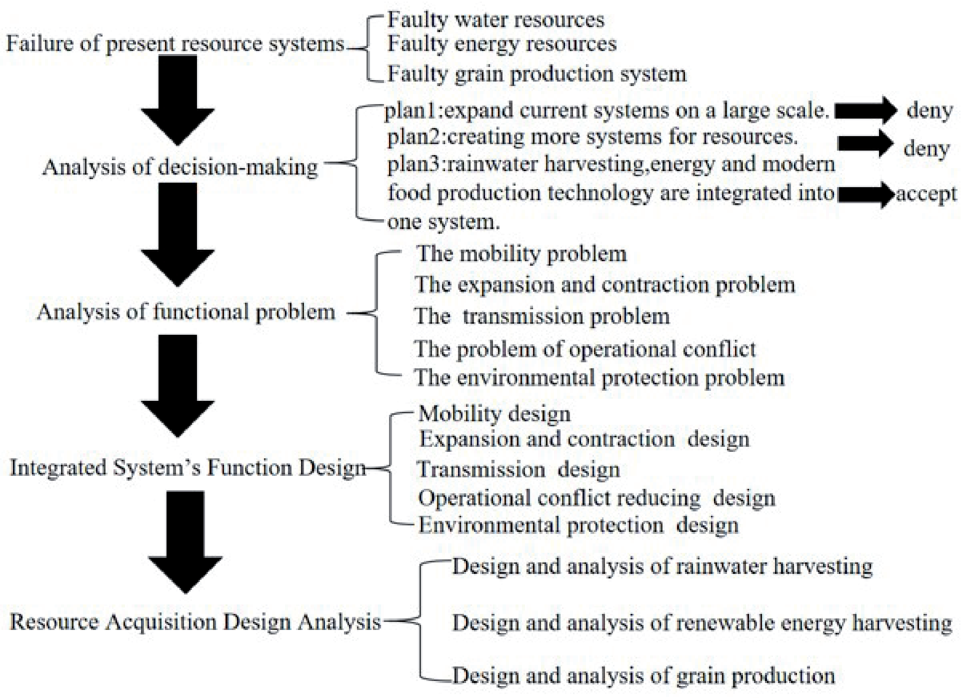

Fig. 1. Integrating water collection, energy and food production based on air film building.

material to collect water resources, develop renewable energy, and increase food production. However, whether this approach is suitable for extreme weather conditions requires design analysis.

Methodology

The above review of the literature reveals that global extreme weather has intensified the demand for water, energy, and food resources. It is therefore imperative to investigate the establishment of a system solution that can be implemented in a relatively short period of time and which will meet the demand for water, energy, and food in order to address the challenges posed by extreme weather events. Accordingly, the new system solution must adhere to the following fundamental principles:

First and foremost, the new system must possess a high degree of resilience, which plays a pivotal role in its capacity to adapt to significant changes in the external environment [17, 18]. In response to extreme weather, the new system should be designed with the flexibility to be constructed rapidly and efficiently, allowing for its establishment within a relatively short time. To meet the high demand for water, energy, and food, the new system should be adaptable in terms of time, space, and resource accessibility.

Secondly, the objective of sustainable development can be achieved through the implementation of recycling practices, such as the utilization of renewable raw materials and the incorporation of green resources [19, 20]. The new system should not only collect and use rainwater, sunlight, wind, and other green resources, but also recycle all kinds of biological and non-biological waste pollutants. As a result, resource acquisition shifts to a long-term renewable mode; it also reduces costs and improves the environment by turning waste into valuable resources.

Finally, the integration of multiple technologies together will bring diverse benefits to resource collection and enhance the capabilities of the resource collection [21, 22]. In view of this, the new system should use integration techniques in such a way as to avoid conflicts in the operation of the system caused by technological incompatibilities.

The experimental methodology employed in this study is based on the advantages of air film in response to the extreme weather that developed under the plan "Integrating water collection, energy, and food production based on air film building," as depicted in Fig. 1. The methodology plan is based on a strategy and the results from previous studies.

Failure of Present Resource Systems

1) Faulty water resources: In the contemporary era, a multitude of techniques are employed to harvest rainwater resources [23]. Except for the exploitation of groundwater, the recycling and reuse of wastewater involves water recycling, steam generation, condensate collection and treatment, collection and treatment of contaminated waters, and hot water supply [10]. In arid regions, the collection of fog water using nano-materials is a means of accessing freshwater [24]. During flood seasons, flood harvesting requires stress-resistant water harvesting networks [25]. Green rainwater harvesting systems are constructed on rooftops for the purpose of collecting rainwater [26].

The majority of the aforementioned methods of rainwater extraction are flawed. When groundwater is overused, it will damage the land and the environment. Recycling and reuse of wastewater will employ relatively complex technology. The quantity of fog water collected is limited. Floodwater harvesting not only requires the right season, but also depends on the availability of a strong rainwater harvesting infrastructure. Only rooftop rainwater harvesting has significant potential, as evidenced by the effectiveness of certain rooftop recharge systems in mitigating the adverse effects of groundwater overdraft [27].

Given the stochastic nature of the location and amount of rainfall, a significant increase in rainwater harvesting will require an increase in the flexibility of rainwater harvesting methods. As a result, the design of rainwater harvesting methods for the new system will need to take into account mobility and the scale of collection. It will make the new system resilient to uncertainties in the amount and location of rainfall and satisfy the long-term high demand for water resources during periods of extreme weather.

2) Faulty energy resources: The increase in fossil-based energy consumption is causing significant environmental issues [28]. Renewable energy technologies, including bio-energy, solar photovoltaic, hydrogen, wind, hydro, tidal, and other renewable energy technologies, have been vigorously pursued to replace traditional fossil fuel-based power generation [29]. Today, mature hydro-power can significantly reduce costs in a relatively short time [30]. The utilization of biomass derived from readily accessible sources, including cow dung, food waste, bio-diesel, and other bio-energy materials, represents a promising avenue for the generation of bio-energy [11, 29, 31]. The current scale of terrestrial and water-based PV capacity has also increased significantly due to the vast amount of land and technological developments [32]. The utilization of an array of wind turbine types, contingent on the strength of the wind, serves to enhance the overall output of wind energy [33].

However, the intermittent nature of renewable energy sources limits the amount of energy they can produce. For example, hydroelectricity is largely dependent on rainfall, while solar and wind energy are also limited by time, weather, and geography [30, 32, 33]. In addition, bio-hydrogen, biogas, bio-fuel, and bio-diesel involve a series of complex technologies such as cultivation, collection, and transmission [31]. Therefore, the implementation of an integrated system capable of serving the aforementioned renewable energy operations will result in a significant increase in the total output of renewable energy sources; it will meet the long-term energy needs in the context of extreme weather.

3) Faulty grain production system: It is anticipated that climate change will result in an increase in the frequency, intensity, and spatial extent of extreme weather events [34]. The occurrence of high temperatures, water shortages, and heavy precipitation will serve to exacerbate the damage to food production [35].

Food production is a complex process that involves a number of factors, including land area, temperature, pesticide use, fertilizer use, and irrigated areas [36]. Nevertheless, the strategic integration of water and technology has the potential to enhance agricultural yields; a recent study has demonstrated that alterations in precipitation levels exert a considerable influence on wheat yield [37]. The application of mulch technology has resulted in a notable increase in rice yields [38]. The utilization of vertical agriculture, coupled with cutting-edge technology, represents a pivotal strategy for enhancing global food production, eradicating hunger, and guaranteeing food security in the future [39].

Unfortunately, food production is currently out of reach in most countries due to water and energy shortages [7]. It can be reasonably deduced that the establishment of a system for the collection of water, energy, and food would prove an effective solution to the problem.

Analysis of Decision-Making

Ensuring effective access to rainwater, energy, and food resources in response to extreme weather events is critical. In order to select the optimum solution, it is therefore necessary to compare the advantages and disadvantages of the integrated system solution with other solutions.

1) Should the infrastructure for rainwater, energy, and food be extended on a substantial scale, it will be necessary to make a substantial investment of both human resources and capital over an extended period. The majority of these inputs may be non-renewable resources, including oil, gas, arable land, and large quantities of building materials, such as reinforcing steel, cement, and concrete. It is clear that this program not only consumes limited resources, but also has a negative impact on the environment, which contributes to the poor sustainability of the solution.

In addition, the solution's ability to attract resources is severely constrained by its slow pace of construction and limited output. It is clear that a program that simply expands existing resource collection systems without integrating resource collection technologies would face significant challenges in coordinating the management of water, energy, and food resources. As a result, it will be unable to achieve the desired integration effects through the establishment of mutually supportive relationships between the resources.

2) The creation of more systems has the potential to enhance resource output, but inevitably entails a greater reliance on non-renewable resources than the above solution. In light of the aforementioned considerations, it can be concluded that this program is also not aligned with the principles of sustainable development. This plan is also constrained by its inherent inflexibility, which limits its ability to accommodate the harvesting of intermittent and uncertain renewable resources. It also does not facilitate mutual support between the three resources due to the lack of integration of the underlying technologies.

3) The integrated system solution combines rainwater harvesting, energy, and advanced food production technology in one system. It exhibits remarkable flexibility due to the inherent properties of the air film material. The integration of resource harvesting technologies enables the system to facilitate a mutually supportive relationship between rainwater, energy, and food. In comparison to the aforementioned two options, the integrated system evinces superior efficacy.

The aforementioned comparison indicates that the following principles should be considered when harvesting resources of rainwater, energy, and food: flexibility, technology integration, cost-benefit comparisons, and strong sustainability.

Analysis of Functional Requirements

In order to achieve the above principles, it is first necessary for the integrated system to equip itself with several functions. Moreover, it should also design the various ways of collecting resources individually. The following section will analyze the problems that the integrated system is designed to address.

1) The mobility problem: In order for the integrated system to function effectively, it must be capable of moving to the designated area and collecting rainwater, and renewable resources. Once the mobility issue has been resolved, the integrated system will be able to collect precipitation, wind, solar, and bio-energy from different locations. The mobility function problem-solving will significantly enhance the resource access capacity of countries experiencing extreme weather.

2) The expansion and contraction problem: The resources that can be collected by an integrated system are contingent upon the extent of the system's collection of resources; the greater the coverage, the more rainwater, energy, and grain can be collected, which requires that the integrated system have the function of expansion. In addition, because of the mobility function, the integrated system facility should have a contraction function. This problem-solving is directly related to the ability of an integrated system to reach a given location and capture sufficient amounts of water, energy, and grain.

3) The transmission problem: The integrated system's synergistic effect necessitates the transmission of collected resources to other sites for the purpose

of supporting the harvesting of other resources. In light of the intermittent and irregular nature of rainfall and renewable energy sources, it is imperative that transmission equipment be designed with mobility in mind. Therefore, the transmission function becomes an issue that must be addressed by the integrated system.

4) The problem of operational conflict: The utilization of a multitude of technologies is necessary to facilitate access to a diverse array of resources. Reducing system conflicts caused by the operation of multiple technologies requires that the integrated system has good technical compatibility. Obviously, the resolution of technical incompatibility issues can enhance the stability and output efficiency of systems that employ disparate technologies.

5) The environmental protection problem: The construction of resource harvesting facilities frequently results in the exploitation of natural resources. Additionally, the generation of a variety of waste and pollutants during the construction and operation of the above facilities has a deleterious effect on the surrounding natural environment, which serves to exacerbate the negative impact of extreme weather on human society. In conclusion, the integrated system should be constructed and managed in a manner that is environmentally sustainable.

6) Summary of functional requirements issues: Based on the preceding analysis, the integrated system necessitates the integration of a comprehensive system to address the interrelated challenges of mobility, scalability, transmission, technical compatibility, and environmental protection. The following five functional issues below are proposed for the integrated system:

Question 1: Does the integrated system have mobile functions?

Question 2: Does the integrated system have the function of shrinking and expanding?

Question 3: Does the integrated system have a transmission function?

Question 4: Does operational conflict exist in the integrated system?

Question 5: Is the integrated system environmentally friendly?

Integrated System's Function Design

In order to effectively address the aforementioned five issues, this paper proposes the design of an integrated system that collects rainwater, generates green energy, and cultivates foodstuffs utilizing air film as the primary material.

In the following, we will study how to make the integrated system have the functions of mobility, telescopic expansion, transmission, technology compatibility, and environmental protection with the characteristics of the air membrane building.

1) Mobility design: The air-film building is an inflatable facility whose primary component is composed of plastic, resulting in a lightweight integrated system [16]. The compact dimensions of the non-inflatable air film facilitate convenient storage [13]. Consequently, the integrated system can be expediently conveyed to designated positions by an appropriate mode of transportation, thereby conferring upon the integrated system considerable mobility.

2) Expansion and contraction design: The inflatable membrane structure is characterized by its considerable volume and length [40]. The air-film buildings can be used to create large temporary venues [14]. As a result, the integrated system can cover a significant area. Because of its large coverage area, the integrated system can then harvest large amounts of resources such as rainwater, wind, and solar, and even provide greenhouse services for food production.

In addition, the non-inflatable air film has extremely low shrinkage due to its small size and lightweight, which not only makes the integrated system easier to handle, but also allows for flexible changes in size and shape depending on the area to be covered [14]. In conclusion, the integrated system comprising gas film as the primary material is better suited to fulfilling the expansion and contraction requirements.

3) Transmission design: The primary material of the air film is a plastic that exhibits elastic properties, which allows the air film to be constructed into objects of diverse shapes, including pipes [41]. Once the integrated system has captured resources in remote areas with limited access, the transportation of gases, liquids, and solids can be facilitated through the use of closed, bendable air-film piping.

4) Operational conflict-reducing design: Designs to reduce operational conflicts can be addressed in three ways. The initial step is to ascertain the significance of resource necessities in accordance with the requisite quantities of water, energy, and food. Subsequently, the resources to be acquired are prioritized according to their importance, and the collection of resources is carried out in accordance with this prioritization to avoid operational conflicts.

Secondly, the integrated system mode is reasonably allocated in order to reduce operational conflict. During the diurnal period, the system collects solar energy, while at night it simulates the growing environment of crops in the daytime.

Thirdly, the composition of resources can be determined based on their input-output ratios, and the chronological sequence of resources to be collected by the integrated system can be arranged based on the optimal resource mix. This approach not only circumvents operational conflicts but also achieves the objective of maximizing revenue.

1) Environmental protection design: The mobile nature of the integrated system renders it particularly lightweight and compact, thus facilitating its storage and recycling without encroaching on agricultural and forest land. Once inflated, the integrated system is capable of floating on water and can also be utilized as a greenhouse to enhance crop growth. Integrated systems

in the above state are more environmentally friendly. It can therefore be concluded that the rational use of the integrated system will not result in environmental pollution.

Moreover, the quantity of plastic necessary for the fabrication and upkeep of integrated systems is considerable. As a result, the recycling and processing of plastics furnish a consistent supply of building materials for integrated systems. This not only serves to reduce the quantity of plastic waste present in the environment, but also enhances the capacity to obtain resources through recycling.

Resource Acquisition Design Analysis

The integrated system consists of rainwater, renewable energy, and food collection subsystems. This section will present the design and analysis of methods for accessing rainwater, renewable energy, and food.

1) Design and analysis of rainwater harvesting: The likelihood of extreme precipitation becoming a regular occurrence in the future is increasing [6]. The rainwater harvesting subsystem in the integrated system will utilize rainwater as a source of water, which is a clean, cost-effective, and environmentally benign resource. In advance of precipitation, meteorological forecasts can furnish the rainwater harvesting system with a variety of data on rainfall, including the location, intensity, and timing of precipitation.

In accordance with the projected precipitation data, the integrated system initiates the preparation of the air membrane facilities in advance. Furthermore, the integrated system's intrinsic shrinkable and movable functions enable the transportation of the system facilities to the designated precipitation location in advance. The expeditious construction and scalability of the air-film building permit the rainwater harvesting system to be established with alacrity prior to the onset of precipitation and be expanded to cover an area capable of harvesting a substantial quantity of precipitation.

Ultimately, the transmission function of the integrated system is employed to establish a connection between the rainwater harvesting system, the renewable energy system, and the food production system, thereby creating an integrated whole. Furthermore, water resources can be transmitted to other subsystems in order to provide them with support.

2) Design and analysis of renewable energy harvesting; The utilization of the air film feature, whereby it is constructed into objects of diverse shapes, allows for the creation of an integrated system that serves as a platform for the installation of wind power facilities. Anticipating the location of wind resources in the recent period, relocating the integrated system to that location in advance, and installing the wind power facilities on the platform. In the event of the aforementioned location proving unsuitable for the efficient collection of wind energy, the platform and associated wind energy generation facility may be unloaded and recovered. The wind energy collection subsystem is capable of harvesting wind energy from all directions with high efficiency, without the need for land occupation or pollution.

The elastic characteristics of the integrated system permit it to float on water. The integrated system is designed to serve as a platform on which a substantial number of solar collectors can be placed. During days of elevated temperatures and abundant solar energy, a considerable number of solar collectors can be placed on the platform, which is situated on the water surface. In instances where solar energy is insufficient or unavailable, such as during a windy night, an integrated system can be substituted with wind energy collection facilities. The above alternative has demonstrated the capability of uninterrupted energy collection on a 24-hour basis. This configuration enables the collection of a substantial quantity of solar and wind energy while simultaneously ensuring the effective protection of water resources.

Ultimately, the transmission of the integrated system is leveraged to establish interconnections and integrate the subsystems of rainwater harvesting, renewable energy harvesting, and food production into a unified system. The transportation of water and energy to the food production system allows for the continued production of bio-energy crops. Crops and wastes can be used to provide a range of energy sources, including gaseous, liquid, and solid energy, supported by transported water and renewable electricity, as well as fertilizers for food production, such as kitchen scraps and crop residues, which can be used to produce biogas [11]. Livestock manure can also be utilized as a source of bio-fuel, while sorghum, sugarcane, and rapeseed can be processed into oil-seed energy [29, 31].

In conclusion, the integrated system has significantly expanded the range of energy types and forms of energy products. The expansion of the integrated system's energy collection area has led to a notable enhancement in energy collection efficiency. The by-products are advantageous for use as food fertilizer, with the main cost being the use of a significant amount of waste [11]. The sustainable development of energy sub-systems has been more fully realized.

3) Design and analysis of grain production: The initial step involves integrating the rainwater, renewable energy, and food subsystems into a unified system through the use of transmission. The integrated system transmits rainwater, renewable energy, and organic fertilizer to the food production system, thereby providing the latter with a certain amount of fertilizer and sufficient water to increase food production.

Secondly, the utilization of air-film buildings allows for the creation of a substantial enclosed space for the food system. In this space, the energy delivered can be employed to regulate water, light, temperature, and fertilizer within the space, thereby establishing an all-day environment conducive to the growth of food

Table 1. The evaluation of the three different plans shows the evaluated satisfaction of the five questions in case of extreme precipitation.

Assessment plans	Assessment index	Mobility	Shrinking and expanding	Transmission	Less operational conflicts	Environmentally
Plan1	Needs for design	+	+	0	0	+
	Meet	0	0	+	+	0
Plan2	Needs for design	+	+	+	+	+
	Meet	0	0	+	0	0
Plan3	Needs for design	+	+	+	+	+
	Meet	+	+	+	+	+

crops. This environment enables the food to continue growing at night in a manner similar to that observed during the day, effectively reducing the food production cycle. As a result, the food subsystem increases the number of harvests and the overall yield of food through the application of scientific and technological principles.

Ultimately, in the event that the requisite resources are available, the food subsystem can facilitate the planting of crops in a season other than that in which they are normally cultivated, as well as the conversion of crops that are unfeasible due to harsh growing conditions, but which are more productive.

In conclusion, the integrated system has significantly increased the amount and type of food produced by the resources between support. After food needs are met, fast-growing, high-yielding, adaptable energy crops, including sorghum, sugarcane, and vegetable oils, can continue to be grown to produce bio-diesel, fuel ethanol, gas, and other energy products to meet diversified energy needs. This will not only provide mankind with unlimited prospects for energy development and solve the energy demand crisis, but will also reduce the generation of industrial waste and contribute to environmental protection.

Discussion

In order to mitigate the impact of extreme weather, it is imperative that governments act expeditiously and implement measures to prepare for such occurrences. However, the current resource collection system is already difficult to adapt to the current extreme weather. Coupled with the fact that the world is in the midst of persistent epidemics, wars, droughts, floods, economic downturns, and other unfavorable factors, it is a wise choice to change the existing model of resource collection to be more resilient.

It is imperative to emphasize the principles of resilience and technological integration in the design, which endows an integrated system with the capacity to withstand the intricacies and variability of extreme weather. The principles can be exemplified by the five functions expressed in this paper, which demonstrate how integrated systems can efficiently and environmentally friendly cope with extreme weather. Resilience and technology integration are pivotal in addressing the significant changes occurring globally.

By leveraging the interdependent relationship between water, energy, and food, the integrated system increases the output of resources and ensures sustainability. The integrated system can combine different resources on a single system platform and coordinate the operational conflicts according to factors such as the order of supply and demand, time adjustment, and the difficulty of acquiring resources, so as to realize technical compatibility.

The system collects resources in an environmentally friendly manner, which will contribute to the alleviation of the negative effects of extreme weather. To cope with the extreme weather, sustainable and environmentally friendly development measures should be promoted, such as rainwater harvesting, the use of renewable energy, the recycling of surplus food, and the use of waste such as plastic as the main material for the system.

In light of the aforementioned results, the assessment delves into the three distinct plans for resource acquisition and the mitigation of extreme weather events across the five queries, as well as the assignment of appropriate marks. The assessment criteria are affirmation (+) or negation (0) in Table 1. The comparative analysis of the three schemes to cope with extreme weather reveals that the integrated system, which integrates the interdependent relationship among water, energy, and food collection, is superior to the first scheme, which expands the existing resource collection system, and the second scheme, which establishes a new resource collection system, in terms of resource acquisition type, quantity, cost, technology, and environmental protection level.

Conclusions

In this study, an integrated system using air film as a material was developed to ensure the provision of substantial quantities of water, energy, and food under future extreme climate scenarios. This is mainly due to the fact that the integrated system fulfills functions including mobility, expansion and contraction, transmission, technical compatibility, and environmental protection.

The integrated system makes use of the above functions to realize the principles of flexibility, sustainability, and technologies integrated into resource collection. Thus, the integrated system can transform resource gathering from reactive to proactive, significantly improving the efficiency and effectiveness of resource gathering.

The system is designed in such a way that rainwater, renewable energy, and food production are mutually supportive, and waste can be recycled. Therefore, even in the most adverse weather conditions, the integrated system is capable of accessing substantial quantities of water, green energy, and food. Consequently, it is able to ensure the continuity of normal social and economic activity in such circumstances.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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