CHAPTER 43

THE ROLE OF NEW AND GREEN WATER RESOURCES IN LOCALIZING WATER AND FOOD SECURITY UNDER ARID AND SEMI-ARID CONDITIONS

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INTRODUCTION

WATER, food, and energy security are essential to the healthy future of the planet. The three systems are interconnected and are highly affected by dynamic factors such as rising populations, changing economies, resource governance, health risks, climate change, and international trade. These dynamic factors (i.e., stresses) increase pressures on natural resources, and reveal the challenges and security risks associated with maintaining business-as-usual resource allocation and management practices. By 2050, the global water, food, and energy demands are expected to increase by 55 percent, 60 percent, and 80 percent, respectively (IRENA, 2015). The interlinkages among the resources and stresses are especially pronounced in drylands, and the need to better understand these connections is critical. Dryland countries face increasing water and food security challenges which are tightly linked to strategies governing the allocation of scarce water and food resources, often developed within separate disciplinary silos. However, future water and food insecurities are chronic impediments to economic growth and social stability (WEF, 2011). Therefore, moving away from narrow and siloed planning for the future of the primary resource systems towards more holistic approaches will be integral to maintaining the sustainability of national economies. Providing sustainable solutions to overcome current water and food security challenges will require the scientific community to: (i) better understand the water and energy services, and the food supply chain (ii) study the interlinkages and quantify tradeoffs among different resources in identified hotspots; (iii) develop innovative decision support tools to assess resource requirements and associated social and environmental risks, reflecting different water, food, and energy resource allocation strategies in drylands countries; and (iv) provide the resource nexus services and supply chain community with science-based analysis to help them quantify tradeoffs related to primary resources decisions.

The problem of food security and water security in dryland countries is most profound. These countries seek to maximize their local food production under harsh environments, with limited water resources and very little arable land. Under such conditions, building science-based knowledge regarding optimal usage of the available natural resources of water, land, and energy, both renewable and nonrenewable, is urgent. In addition, the negative consequences of climate change on spatial variability on water and food supply, in general, will outweigh the positive (Godfray et al., 2010).

The most probable climate change scenario anticipates that the drylands will get dryer and the wetlands will get wetter. Dramatic changes are expected in the availability and spatial distribution of renewable fresh water, both blue water (water in rivers, lakes, and underground), and green water (rainwater evapotranspiration and storage as soil moisture) (IPCC, 2013; Milly et al., 2008). Therefore, dryland countries are expected to face more severe and harsh environments, and a reduction in nonrenewable arable land and conventional water resources. In such a situation, innovative technologies that are based on a scientific understanding of the interactions and optimal usage of these resources (environment, land, water, and energy) are urgently needed to achieve a reliable level of water and food security.

In this context, we are talking about two domains of research: the water–energy domain and the water-land-atmosphere domain. In the water–energy domain, efficient techniques for capturing solar energy and developing energy-efficient treatment technologies for nonconventional water are being progressively enhanced. In this domain, more research is needed to quantify and understand the global requirements of energy for water production (Liu et al., 2016), and thereby the quantitative understanding will enhance our knowledge of the water–energy nexus system and its sustainable management, and provide an integrated picture for policymakers. The first research domain requires a framework that integrates innovative techniques and understandings to address a triple bottom line question: at what cost, at what level of treatment, and to what end-use? In the water-land-atmosphere domain, nonconventional water (greywater, wastewater, brackish water, produced water from oil and gas industries) and green water have the potential to become major contributors towards bridging the supply–demand gap in water and food securities in dryland countries. In this second domain, research efforts should focus on the adoption of localized solutions to manage and conserve natural resources in the face of the increasing water and food demand. Having said that, the two domains interface in providing low cost and low-carbon treatment technologies for safe water to secure food production. This chapter presents the challenges facing the water–energy domain and the water-land-atmosphere domain.

The chapter also proposes solutions that may apply to both domains and links these possible solutions to water and food security.

WATER RESOURCES FOR BRIDGING THE WATER SUPPLY–DEMAND GAP: AVAILABILITY AND CHALLENGES

Renewable blue water resources

Renewable fresh water resources are dependent on the spatiotemporal distribution and intensity of precipitation. The hydrological cycle shows that precipitation can be stored as freshwater in either (i) surface water bodies (rivers and lakes) and underground (groundwater); or (ii) in soil profiles where it can be evapotranspired by plants. The first portion has been given the name of blue water, while the second portion has come to be called green water. Currently, only 10 percent of the maximum renewable blue water and 40 percent of green water has been utilized to meet global water demand (Oki and Kanae, 2006). It is the spatiotemporal distribution of water resources, according to climate conditions and climate change, which concerns society. In addition, societal systems using land and water have an impact on the quality of water resources. Vörösmarty et al. (2010) found that 80 percent of the world's population is exposed to high levels of threat to water security due to these activities. Threat levels are, fortunately, decreasing in response to investment in water technologies and infrastructure and the reduced intensity of water consumption. However, the populations most impacted by both climate change variability and threats to water security are in developing countries, which are often drylands. Policymakers in dryland economies need to have access to: (i) a better understanding of blue and green water metrics and management options; and (ii) dynamic maps of hotspots of water–food scarcity and security. The water-food-energy nexus can serve as a two-way interface and platform between the soil and water scientific community on one hand and policymakers and society on the other hand. It is also a useful framework for identifying the problem hotspots and subsequently devising the most feasible actions and policies to be adopted and implemented by policymakers.

The nature of blue water makes it visible and accessible. Infrastructure to store and mobilize it is readily understood and its investment potential is easily communicated. But blue water is very vulnerable to pollution by industries. Most dryland communities are prioritizing the use of blue water for domestic and industrial water consumption rather than for agriculture. Water for irrigation usually accounts for more than 70 percent of the blue water consumption. As an example, the State of Texas faces a projected 30 to 40 percent gap in water availability by the year 2060 (a total of 8.24 billion cubic metres) to satisfy growing demand (TWDP, 2012). The Texas Water Development Board

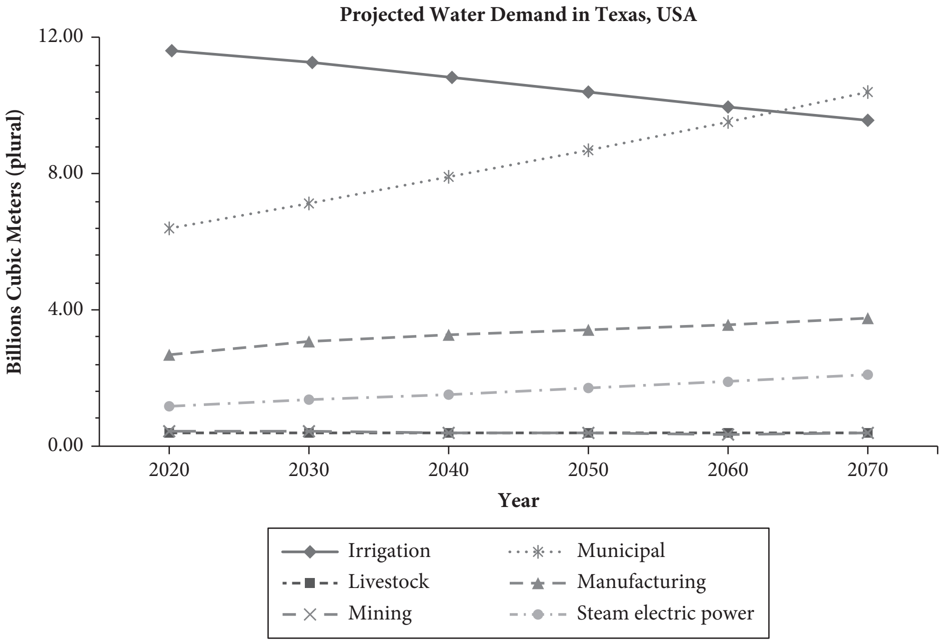

FIGURE 43.1 Projected water demand in Texas. The Texas case can serve as a useful example for dryland countries. More renewable blue water will be allocated for municipal, manufacturing, and electrical generation than for food production in irrigation and in livestock production. New water and green water is expected to bridge the food production water demand

Source: (TWDB, 2012)

(TWDB) plans to bridge the gap by reducing and recycling industrial and domestic water, particularly by focusing on increasing (i) the utilization of renewable blue water resources to bridge 60 percent of the gap, (ii) water conservation practices (24 percent), and (iii) nonconventional water supply such as desalination (16 percent). However, TWDB has prioritized the use of fresh blue water to meet the domestic water demand over the food production demand (irrigation and livestock), as shown in Figure 43.1. The domestic blue water demand in Texas is expected to increase from 6.4 billion cubic meters (BCM) in 2020 to 10 BCM in 2070. Conversely, the agricultural blue water demand is expected to decrease from 12 BCM in 2020 to 9.6 BCM in 2070. Of course, the demand for water for irrigation and livestock uses will increase. Policymakers should also keep in mind that renewable green water will also play a pivotal role in bridging this supply–demand gap.

Renewable green water resources

The concept of green water was introduced in 1995 by Falkenmark (FAO, 1995). Unlike blue water, green water resources have thus far received very little attention from the soil and water community of science and policymakers. One main reason for ignoring green water is its lack of visibility, despite its importance in food production, in support of natural vegetation, and in underpinning biodiversity. Green water in agro-ecological systems can be compared to the blood circulation in animals, as it forms an essential component of the system. Compared to blue water, green water accounts for 87 percent of water used in global crop production (Liu and Yang, 2010), and it also accounts for 60 percent of the global food production (Cosgrove and Rijsberman, 2000; Rosegrant et al., 2002). Therefore, water and agro-environmental scientists need to (i) better recognize the importance of green water (Falkenmark and Rockström, 2006; Gerten et al., 2005; Mohtar et al., 2015); (ii) better understand the kind of knowledge required to be shared with policy makers (Mohtar et al., 2016); and (iii) build a framework for transferring such knowledge to decision makers. Only when the scientific community achieves these goals will policymakers properly recognize this precious source of water and give it the attention it is due.

Policymakers, in particular in dryland areas, should be interested in understanding the potential of green water in improving water and food security and the economic value of investing in green water resources. Several studies have provided evidence demonstrating the important contribution of green water in water and food security. Schuol et al. (2008) showed that more than 80 percent of renewable fresh water in Africa is in the form of green water. Kauffman et al. (2014) highlighted the potential economic value of investing in green water resources by introducing the green water credit concept: According to their study, investing in developing only bench terraces in Upper Tana Basin in Kenya would generate a total revenue of around US$10 million annually considering the impact on agricultural production, domestic water use, and hydropower generation. Kauffman et al. (2014) delivered a message to decision makers that, while most dryland countries focus on blue water resources, a special focus on green water is worthwhile and could perhaps prove more productive. Considering the financial, socioeconomic, and scientific capability in many dryland countries to implement blue water infrastructures and treatment plants, we support the call of Kauffman et al. (2014) for greater attention to green water.

Green water is dependent on the interactions among the three natural entities of the soil-plant-atmosphere system, where soil forms the infrastructural medium of interactions. The sustainability of these natural entities is key to addressing the water and food crisis of today and the future, especially in dryland countries. Managing these resources requires a quantitative approach for accounting of green water, which in turn requires further investigation (Mohtar, 2015). The basis of this approach should be the recognition and characterization of soil as a naturally organized physical medium providing the physical conditions for life or development of the numerous biotic and abiotic processes that are taking place in soils (Braudeau and Mohtar, 2014; Braudeau et al., 2016). In addition to the existing gap of recognizing the soil medium in quantifying the green water, Mohtar et al. (2015) identified other two research gaps for better accounting of green water. The first is to characterize the soil structure through measurable parameters, each of which describes a specific characteristic in a soil–water system. These parameters can be used as an indicator of soil quality and productivity, and can also be used to track the behavior changes in soil–water holding capacity (i.e., the capacity of soil to hold green water within a specific soil-plant-atmosphere system). Second, research is needed regarding how to transfer this gained scientific understanding at field (local) scale to the policymakers at the national level scale, whether from policy to practice or from practice to larger scale. Further discussions about the role of soil in water reuse schemes are presented in a subsequent section.

Nonconventional water resources: New water resources

The reuse of nonconventional sources of water (new water reuse) has the potential for bridging the supply-demand gap in dryland countries without further exploitation of natural water resources, and with minimal threat to human water security and environmental biodiversity. The adopted treatment technologies impact the costs of nonconventional water treatment, while reuse guidelines, regulations, and standards additionally impact how the water can ultimately be used.

Different water reuse stakeholders have different concerns about water reuse systems. Water scientists and engineers are primarily concerned with the sources of new water and how to improve the removal efficiency of organic matter, pathogens, salts, heavy metals, and other hazardous components from these new water sources. Water operators and governmental agencies are concerned that new water meet quality standards and that end-users are using the proper quality water. Societal attitudes are generally driven by public disgust or religious factors associated with the idea of using wastewater. Policymakers must usually consider all of the above to achieve sustainable and resilient plans to bridge the water supply-demand gap. Therefore the success of new water reuse plans are dependent on interconnected factors, including the quality of new water, technology and treatment efficiency, public acceptance, socioeconomic and sociopolitical aspects (Garcia-Cuerva et al., 2016; Salgota et al., 2004), governance and its role in sustainable planning through stakeholder participation (Frijns et al., 2016), and most importantly the long-term impact on environmental health and consequently human health.

Accordingly, managing new water reuse in dryland countries needs to be based on an assessment of cutting-edge, research-informed best practices and knowledge. This assessment must i) identify the potential sources of new water (treated municipal water, greywater, gas-to-liquid treated water, gas and oil produced water, construction dewatering, cooling water, etc.); ii) consider treatment technologies, their energy and environmental footprints, and treatment efficiencies; and iii) address safe and socially accepted end-use potentials. Normally, end-use potentials are the most challenging issue and still considered a very active research area given their long-term impact on natural resources (mainly environment) and, consequently, human health. The source of new water and the potential end-use are significant.

A good but challenging example for the development of sustainable new water reuse is the produced water and the treated hydraulic fracturing wastewater from the oil and gas industries. This new water is chemically enriched water, and there is very limited knowledge of the risks associated with its disposal and reuse. Shariq (2013) highlighted the uncertainties associated with the potential reuse of treated hydraulic fracturing wastewater for irrigation purposes, including its impact on the soil and food health and quality. The chemical nature of this new water as well as its toxicity, biodegradability, disinfection byproduct, and physical and chemical interactions with soil, plants, natural water resources, and ecosystems are open questions regarding its reuse.

Considering water and land scarcity in drylands, several research efforts have addressed the challenge of water, food, and energy demands under such harsh conditions. These studies produced considerable knowledge, information, and lessons learned. However, this knowledge remains scattered and disconnected. To overcome this issue, current and future research efforts need to be directed toward two research questions: i) How can the research efforts in drylands around new water reuse be integrated into a single platform that unifies the efforts towards the grand challenge of water and food security? ii) As natural resources (water and land) are limited and in many cases nonrenewable, how can the long-term impact of reuse applications on land health and productivity be tracked and predicted? These questions point to the need for an interactive platform to gather scientific-based, dynamic evaluation of executed management plans that account for the financial, economic, environmental, and social aspects of water reuse, while still achieving the optimal target goal of resource sustainability. Novel integrated methodologies based on a comprehensive scientific understanding of multiple interactions and optimal usage of these resources are needed to achieve resilient, sustainable resource systems.

Research efforts should be directed towards answering a triple bottom line question of new water reuse: at what cost, at what level of treatment, and to what end use? The research effort should build a framework or protocol to consider the cost of treatment, the treatment efficiency and technology used, and the range of end use categories. The end use categories will require different inputs, starting from low cost—low efficiency to high cost—high efficiency treatment technologies, where each of these categories has a well-defined threshold. Several threshold types can be identified to define each end use category: Thresholds should be defined according to technical, socioeconomic, environmental, soil and plant health, and human health criteria. These threshold values can build on existing knowledge and water reuse guidelines and standards, while others may require further research for calculating their footprints' impacts. This framework can facilitate an effective dialogue among stakeholders concerning trade-offs analyses. The trade-offs are between scenarios regarding the required intervention, in our case, of the needed infrastructure vs. potential effects of reducing water demand and overall consumption. Trade-offs analysis is a function of both stakeholder interventions and footprints calculation—therefore, it will provide a platform for integrating stakeholders' perspectives including water scientists and engineers, socioeconomists, environmental agencies, food security programs, policymakers, and the community at large.

The challenge of water reuse in food security: Dynamic changes in soil quality and productivity

The potential reuse of new water in drylands will be directed mainly to agricultural and industrial activities. However, agricultural water reuse is expected to be dominant, and the development of sound policies and strategies for water-food security will be critical for the future health of dryland communities. Drylands are facing an increase in the amplitude and frequency of dynamic stresses that make providing these policies and strategies a great challenge. In our opinion, one limiting factor for such a challenge is the absence of adequate and standard quantitative representation that reflects both the nature of the resource and its natural functionality. Such a quantitative representation enables the establishment of interdisciplinary linkages among various disciplines dealing with the same resource. As an example, we focus on a vulnerable and nonrenewable natural resource, soil. Soil must be a primary consideration for policymakers in building and enhancing sustainable water and food security programs in any nation. As a living medium, soil is a hierarchically organized medium where each soil type has its own unique organizational 'structure'. This unique organization enables the soil to perform various functions: it maintains life and biodiversity, contributes to *energy* production and *climate* sustainability, and forms the infrastructure medium for producing *food*, fiber and fresh *water* for more than 7 billion people.

Soil health and productivity in drylands are very vulnerable. Therefore, advanced quantification of the potential of soil to produce food and perform its natural functions is imperative. Nowadays, there are two approaches to assess soil quality, and thus its functionality: The first is the indicator-based approach, which is a more universal approach in that it uses relatively easily accessible data; however, the applicability of this approach has been questioned due to the variability of soil types and agro-ecosystems (Schjønning et al., 2004). The other approach, the management-based approach, is more related to a specific management practice and thus more site- and soil function-specific. The latter approach could be more favourable once the variability of soil, climate, and practices across the globe as well as the need for more accurate assessment of the management practices on soil quality are considered. However, both approaches lack two important aspects: i) a quantitative assessment of agro-environmental 'human' practices on soil organization and functionality (soil health) due to the lack of representative and measurable parameters that describe this hierarchical organization and its thermodynamic interactions with the surrounding environment (air, water, plant); and thus ii) the ability to predict the future behavior of soil functionality. Making these quantitative-based predictions possible opens the door for more focused solutions to the urgent question about the long-term impact of new water reuse on the future quality of this valuable and nonrenewable natural resource (Rusan et al., 2007), and thus our water–food security (Mohtar, 2015; Mohtar et al., 2015). Quantitative predictions will also serve to inform decision makers of the potential impacts of water reuse programs. Figure 43.2 presents the hydrostructural pedology approach (Braudeau et al., 2016)

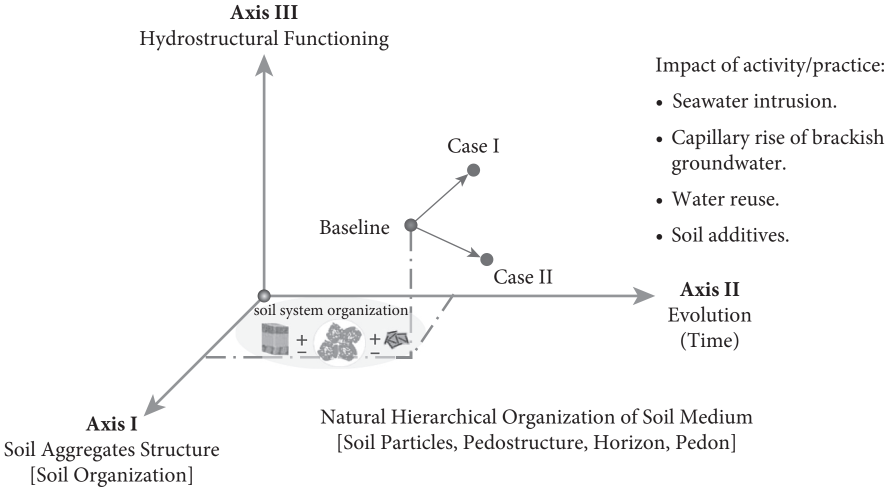

FIGURE 43.2 Hydrostructural pedology approach for studying the short/long term impact on soil structure, heath, and productivity

that enables the quantitative tracking of the impacts of new water reuse and other natural stresses associated with climate change on soil structure, and hence soil health and productivity.

VALUING NATURAL RESOURCES: TOWARD INTEGRATED VALUE-BASED POLICYMAKING

A key condition for overcoming water and food security challenges in drylands is greater knowledge within the scientific community about how to inform decision makers and policymakers of the gained scientific knowledge. Knowing what and how to inform policymakers is as important for scientists as gathering the needed knowledge. The scientific community needs to work side by side with society and decision makers to develop a holistic, transdisciplinary, and inclusive multistakeholder platform for resource valuation and allocation. The water-food-energy nexus provides the platform that allows the identification of local and site-specific tradeoffs and hotspots, which may facilitate dialogue among stakeholders and better inform decision makers of what they need to know (Mohtar and Daher, 2016; Mohtar and Lawford, 2016). Developing a resource valuation system can integrate the gained knowledge into one holistic framework and provide a significant, integrated, and comprehensible picture for decision makers. For example, agricultural intensification to increase biomass production has been promoted as a solution for global food security. This increase in biomass production is associated with an increase in the water and energy footprints. The efficiency of

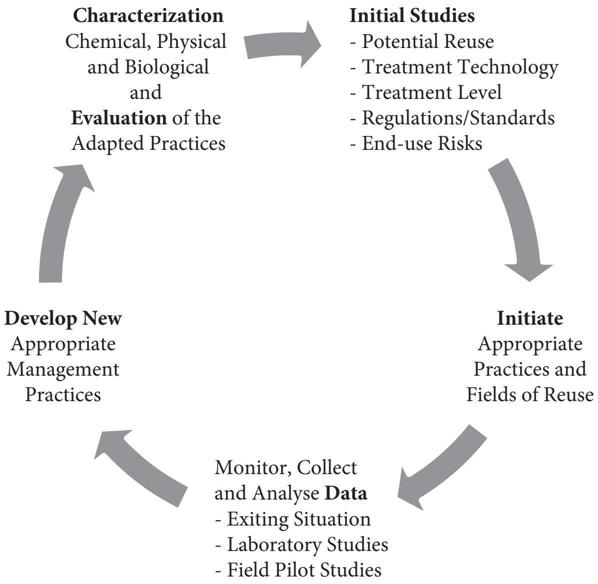

FIGURE 43.3 Adaptive management cycle for the new water reuse

resources used in these scenarios are of course important, but it is not everything; valuing the resource usage and quantifying its associated environmental, social, and economic impacts is more significant in shaping sustainable and resilient decisions. For instance, Saudi Arabia decided to become a wheat self-sufficient country in the mid-1970s, but it was the introduction of such a valuation system that prompted a shift in policy by 2003. There are many similar examples in different parts of the world.

Building on the lessons learned, drylands face a crucial need to build sustainable, resilient, and adaptive resource management strategies that deliver high resolution and holistic decision support tools tailored to local conditions. Therefore, the valuation, impact quantification, and tracking systems need to be integrated within an adaptive management cycle (Figure 43.3). The cycle should cover six fields: characterization of new water, end-use and associated risks, treatment technologies, soil/plant quality and safety, regulations and standards, and cost efficiency of the adapted practices. This integrated system will provide the holistic understanding for all stakeholders to better answer the triple bottom line question identified earlier: at what cost, to what level of treatment, and to what end use?

CONCLUSION

The global water and food security challenge is a multiscale issue. High level government and intergovernmental water strategies and policies are typically conceived at large spatial scales. However, much of our understanding of the processes determining water's availability for food production is based on studies at smaller scales where soil processes carry the burden for most of the anthropogenic and environmental interactions, and thus remain the center of science and modeling research.

The strategies and policies currently in place to address the water and food security challenge are facing two dilemmas: they are not firmly based on scientific evidence and thus their effectiveness remains questionable by the scientific community; and the incomplete transfer of knowledge across scales makes it difficult to evaluate the ultimate impact of these strategies, policies, or management practices on the entire agro-environmental system. Consequently, the scientific community is unable to understand the effect of small-scale processes on the larger-scale view. These two issues are responsible for most of the problems related to interdisciplinarity uncertainties of agro-environmental data and sustainability estimation.

Green water, which is underappreciated but still a critical resource for solving the global food security challenge, is a showcase of the importance of making the linkages between science and policy. In addition, alternative and nontraditional new water resources hold huge promise to provide water for food production. However, issues of clean and low cost treatment technologies as well as the impact of treated water reuse on soil and human health must be integrated into reuse strategies.

Finally, informing policy makers is not limited to communicating the efficiency of any single scenario, but it must also consider the value of the resources used for achieving the target.

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