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Review Article

Water, Energy, Food, and Ecosystem Nexus in Singapore: Challenges and Perspectives

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Abstract *- As the global population persists to grow exponentially, fundamental changes are expected to occur in the next 50 years. Accompanied by the interplay of essential resources for human beings' continued existence, livelihoods, procreation, and advancement represent a food symbiosis. the prognosis for a seamless transition for the WEF symbiosis is, at best, alarming. Given the pandemic shutting of various essential services such as aviation, food, logistics, and import and export trajectories, there is a considerable shortage in critical information for informed decision-making on urgent needs of WEF symbiosis upon recovery. in an attempt to review the key opportunities and challenges of WEF, this study uses the framework of the business model evolution of an innovative and knowledge-intensive industry. It utilizes a circular evaluation technique to identify which parts of the applied business structures indicate transition. the results suggest that the business innovation process in the WEF sector is consistent with the disciplines of the circular economy. Nevertheless, this trend is the result of a small nation making efforts for sustainable development. Moreover, it demonstrates the emergence of a circular economy as an economic issue as it is an ecological predicament.*

Keywords *- Water–energy–food (WEF), Sustainability, ecosystem, Food security, Business models.*

I. INTRODUCTION

We live in a world where we continually witness the fighting for resources, such as the water-energy-food (WEF) security nexus, and potentially a cause of conflict in many parts of the world. the premise in determining a more sustainable food supply involves a system of measurement and tools better to understand the effects of food systems on the environment, generally characterized by land, water, air, and biological ecosystems (Fanzo, Cogill & Mattei, 2012; Ingram 2011). the bulk of water sources (more than 70%) is being used for food production, industry, household use, and electricity generation. the remaining areas, abundant in hydrocarbons, also require water for the energy production process, invariably causing heavy water pollution. All these divergent needs for water from energy and food production can also create circumstances in which parties possess mutually incompatible goals, frequently arising from a mismatch of social values and structures. Therefore, debates over transboundary water supply, intertwined with energy, have become more intense in the last years. Moreover, global climate change is expected to have an escalating negative effect on the water availability pattern during the year. the growing necessity for water worsens this because of population and economic growth, increased temperatures, and a significant rainfall reduction.

The worldwide demand for Water–Energy–Food (WEF) food symbiosis is undeniably increasing, propelled by rising population growth, development, and prosperity. Within an increasingly convoluted food supply, diminishing sources, changes in climate, and potential geopolitical conflicts, worldwide food supplies streams are unpredictable and may be unable to keep pace with demand. for example, at about 720 square kilometers, Singapore is a modest and highly-urbanized city-state. However, due to opposing land usage requirements (e.g., industrial and residential uses), less than 1% of Singapore's acreage is utilized for agriculture, and most food sources are imported. This causes susceptibility to unpredictable food supply and prices and overseas food safety incidents.

In similar veins, the COVID-19 pandemic has given rise to millions of infections and fatalities globally, altering radically our understanding of standards and public health affecting the population. in the food arena, it is no exception, as the effects of this "Black Swan" socio-economic event (Reid et al., 2020) has altered our thinking, buying, and food consumption by expediting earlier innovation trends (Askew, 2020), marking a "before" and "after" period.

As an interim measure, the pandemic impacted the food sector in causing labor shortages (e.g., lack of workers owing to infections and quarantine measures), the closure of factories, food scarcities on supermarket shelves, and instances of tight cash flow for the operating

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companies (Reid et al., 2020). Additionally, the impact of climate change on the sustainability of the food supply is another area of importance. for example, the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC) (Change, 2014) underscored the consequences of water shortages and soaring temperatures on harvests and the elevated food costs and dwindling food security that may result (IPCC, 2014). While sustainability issues are conspicuously missing from most evaluations of food security, addressing the growing need for nourishing food notwithstanding dwindling resources has vast socio-economic ecological repercussions.

We are entering the threshold of a significant global recession (Guan et al., 2020), missing vital information for the recovery. the daunting task of monitoring developments and projecting attitudes about rising technologies, services, and consequences for transiting past COVID-19 are handy, as outlined by Busse and Siebert (Busse & Siebert, 2018) and Suanda et al. (Suanda et al., 2018).

From a longer-term view, the pandemic certainly influences the entire food chain in four principal areas: food safety, bioactive food ingredients, food security, and sustainability (Galanakis, 2020). Across a long contemplative lens, valuable exemplars extracted from previous devastating global events, such as the Spanish Flu or Black Death, where creativity has resulted in paradigm changes in disruptive technologies. Consequently, there is a greater emphasis on innovative technologies to sustain the food industry in the COVID-19 pandemic (Munekata et al., 2020).

The interdependency of water, energy, food security**,** and natural resources – water, soil, and land reinforce that security. Nexus provides deeper insight into the collaborations of water, energy, and agriculture policies. It offers a conscious and precise framework for establishing appropriate trade-offs that preserve the resilience of ecosystems. This paper will argue that ecosystem of WEF aims must eventually be abetted to realize sustainability. Therefore, the mutual concession between these three goals must be judiciously calibrated based on supporting proof. These challenges must and can be addressed by innovative solutions for future food security and sustainability better management of linked resources. for example, resolving the competing needs of water for energy and water for agriculture and at the same time ensuring needs for sustaining ecosystems. It can be done in an integrated, transboundary, and equitable way to strengthen cross-border cooperation. Particular attention should be given to rising energy sources and lowering expenditure. Finally, relevant actors must quickly find ways to develop primary energy production and increase energy-saving investment through different channels to expand energy self-sufficiency and eventually stimulate the collaborative and effective development of water, energy, and food in Singapore.

By exploring the new generation WEF and Ecosystem Nexus business models, this paper intends to respond to the following research questions: first, at which point does the CE development pivot on a national level? Second, what are the implications for the community/institutions in terms of challenges moving forward for sustainability? Third, it conducts an in-depth literature review on the CE business models to facilitate this. Additionally, the paper will use an assessment criterion on these models to determine their circularity. Along with identifying the level of circularity at the national level, the extra benefit of the paper will be to bring about a best practice model for nations in transition. the structure of the paper will be as follows: section 2 shows the materials and methods. Section 3 reviews the Singapore models of a WEF ecosystem according to a circular organizational criterion. Section 4 presents the appraisal results and then encapsulates the analyzed models' identified circular elements. the recent academic work on the WEF nexus is primarily in terms of security, resilience, sustainability, and synergy and is hardly from the viewpoint of resource symbiosis.

Moreover, the symbiosis theory and system analysis method are seldom used to study the symbiosis between water, energy, and food (Chen & Chen 2021). the perception of circularity and how it can be achieved through the WEF security nexus. It will then emphasize the significance of the symbiotic relationship for pivoting toward the objective of eco-friendly sustainability in the food service sector. Finally, the section 5 will conclude the precedent and direction of WEF security in Singapore in identifying the key challenges to identify the main challenges and epitomize the prospects for future exploration and implementation of the WEF Nexus approach.

II. MATERIALS AND METHODS

According to the Ellen MacArthur Foundation's (2013) circular assessment criteria, the study uses the business models as the methodology approach. Lewandowski (2016) has presented a conceptual foundation for advancing circular businesses models where he has placed prominence on the foundation's ReSOLVE (regenerate, share, optimize, loop, virtualize, exchange) framework. This technique is based on finding circular elements in business models defining their relevance to CE. Table 1 provides a comprehensive narrative of the framework's components.

Table 1. The revised resolve framework

Activity	Narrative
Regenerate	• Utilize sustainable energy and materials • 3Rs - Reduce, Reuse and Recycle health of ecosystems • Restore biological resources to the ecosystem
Share	• Augmenting product utility through shared use, obtain or proprietorship • Enlarge product life by recycle, maintenance (e.g., restore, recondition) or blueprint for durability
Optimize	• Proliferation of resource use by enhancing performance or subcontracting activities • Eliminating waste in manufacturing and logistics
Loop	• Ensuring close material loops by promoting 3Rs - Reduce, Reuse and Recycle
Virtualize	• Dissipate products or services through digital appliances
Exchange	• Engage innovative technologies, materials or processes

(source: authors' adaptation based on Ellen MacArthur Foundation (2013) and Lewandowski (2016))

The metamorphosis in the WEF sectors has arisen with the emergence of open business models. in line with Chesbrough (2007), this empowered companies to concentrate on their core competencies by subcontracting (partially) their R&D activities. the work of external funding by big corporations has permitted smaller businesses and start-ups to come into the market by pursuing specific roles in the value-added chain (product life cycle). As it stands, the existence of such SMEs is not just feasible but very important to the entire economy (Blecharz & Stverkova, 2014; Wach, 2015). This helps promote the concept of a business ecosystem in WEF, where innovation is overseen by a collaborative system of businesses with diverse specializations and sizes. This method invariably lowers operational costs and value-added chain dependency. Besides, it launches new revenue streams by linking different actors in a global marketplace.

Table 2 explains the assessment of the systematic open business ecosystem in WEF models. the 'Networked' business model exemplifies that individual firms will not be able to effectively deal with all of the necessary resources required to have control over the complete value chain (Gay, 2014). Notwithstanding, a fully integrated structure is unsuitable in market trends because of cost and time effectiveness (Marcello, Carroll, Vadnerkar, & Volini, 2015). From fostering circularity, 'Repurposing' and 'Technology brokering' business models are specific proposals of this paper. Besides practical aspects, their entire crux rests on the circular lifespan extension design. It is indicative of being a mediator between science and industry: to bridge several otherwise disconnected initiatives, to find out how existing technologies can be used to create breakthrough innovations (novel solutions) in other markets. the "Distributed partnering" model has certain commonalities with this concept. the concession is that it does not take the product development to fruition but instead make a timely procurement and match suitable application for the product (Roth & Cuatrecasas, 2010). Nevertheless, the perception of the model is contentious and provocative. in part, it broadens the value chain by treading into the process, elevating the final product's marginal costs. in its entirety, its focused brokering interest can accelerate the entire R&D time by usefully acquiring a product use.

Table 2. Regular open business models of the Singapore's WEF industry

Business model	Attributes	Fosters circular transition
Open Innovation based R&D	• Occurs when firms choose to pay more attention to their core abilities and farm out their R&D activities.	Yes
Networked	• The transparency of the ethnocentric firms. • Differing arrangement of collaboration as a result of individual requirements. • Effective supervision of resources through leveraging resources/capabilities of other firms.	No Yes Yes
SQA excellence	• Singapore Quality Award Model. • Application of self-assessment based on specific criteria: e.g., execution and/or achievements of essential actions.	Neutral Neutral
Fully diversified	• Multinational corporations exemplar. • Enlargement of principal/key business in order to supply associated products. • The tools are investor, cooperation, consolidation of companies or assets through various types of financial transactions.	No Neutral Yes

IP-oriented	• It relies on Intellectual property rights and copyrights. • Preservation of Intellectual property rights is an important point. • the firm offers or sublicenses all the information on its repository.	Neutral Neutral Yes
Repurposing and technology brokering	• 3R model: Finding a changing or active particle for one intent and employing it for a different usage (e.g. transposing previous ingredients to new diseases). • Copyright administration is a crucial activity, • Mediator between science and industry: to bridge several, otherwise disconnected industries, to find out how existing technologies can be used to create breakthrough innovations in other markets.	Yes Neutral Yes
Distributed partnering	• Multinational Companies (MNC) identify potential products in pre-commercial stage. • They make timely procurement and match suitable application for the product. • Next, they sell it to local small-medium enterprises which conclude the development.	Neutral Yes Neutral
Outcome driven	• Founded on the "Implementation pay" principle, • Application of specific methods to determine performance. • Significant impact on pricing in copyright security period. • the primary patterns are value and compensation.	Yes Neutral Neutral Neutral

(source: authors' adaptation based on Segers, 2017)

The "Bundling" model is a more sophisticated edition of the earlier cited "Networked" approach in the dynamic evolving business environment. Its attractiveness is its participation in cross-sectoral collaboration. A cross-sectoral data (knowledge) flow would guide and steer the future of innovation groups and beyond recent heights of cost-effective resource management. There is evidence that even small-scale businesses like SMEs can work together with large companies (MNCs) beyond their industry (Segers, 2017). the importance of "the 'Crowdsourcing" approach, as demonstrated by large companies (e.g., MNCs), must be construed to small initiatives. the ability of social groups consistently remains a defining component of social advancement has waned over the past century. However, presently their exerting impact has begun to dominate yet again. Business models take advantage of the intangible community capital (e.g., energy enterprises) (Fogarassy, Horvath, Kovacs, Szoke, & Takacs-Gyorgy, 2017a). the "Virtual collaboration" model invites a paradigm that rests on the centrality of IT. the farming out of R&D activity shows a fundamental aspect of this approach. Notably, the added value is undeniably the intellectual virtual network to develop new frontiers (Sabatier, Mangematin, & Rousselle, 2010) (see table 3).

Table 3. Data-driven open business models of singapore's wef industry

Business model	**Attributes**	**Fosters circular transition**
Bundling	• A cross-sectoral data (knowledge) flow would guide and steer the future of innovation groups and beyond recent heights of cost-effective resource management. • SMEs forge alliances with MNCs outside their own industry	Yes Neutral
Crowdsourcing	• Large firms have mostly applied it so far. • They embark on challenges to mobilize external resources. • Obtain peripheral (outside) ideas from the global scientific community via virtual networks.	No Yes Yes
Virtual collaboration	• Small-scale research companies utilize external resources to work on new innovative trajectories. • the added value remains in the formation of the network. • Provides access to own resources and as well obtains external ones. • the centrality of IT. • Such firms are entirely reliant on their collaborators.	Yes Neutral Yes Yes No

Software as a Service	• A bioinformatics model. • Provides consulting service and software to support data management and many activities. • Reduces material intensity by the employed platforms.	Yes Yes Yes

(source: authors' adaptation based on Segers, 2017)

III. SINGAPORE MODELS OF A WEF ECOSYSTEM

A. Circularity and food service supply: Safeguarding Singapore's Food Security

Before the Covid-19 pandemic, the sterling expansion of the world economy and individual industries has unfortunately negatively impacted the environment. As for food services, these impacts are epitomized by excessive usage of energy, water, and substantial wastage (Higgins-Desbiolles et al., 2019). Global policy-making has widely accepted the need to curb these impacts at the upper echelon. (United Nations, 2021). Global land degeneration is also a significant challenge for food production. It can be traced to the genesis of the driving force of urban sprawl, economic growth, greenhouse gasses (GHG or GhG), and untenable land usage. Agribusiness is anticipated to provide food for a rising worldwide population while still accommodating requirements for renewables and the obligation of the ecological community, for example, the provision of nutrient cycling and lowering the amount of carbon footprint in the atmosphere to reduce global climate change. Regardless, the present framework of farming and husbandry discredit these expectations. the segregation of produce and animal husbandry has pivoted towards destructive ecological concerns, and eco-clean energy has yielded concession amidst food and energy production. Furthermore, the challenges between WEF are aggravating the agricultural land vis-à-vis climate mitigation due to carbon appropriation, supply, and cycling of nutrients, along with environment for biodiversity (Schulte et al., 2019; Staes et al., 2018). Synchronized upkeep of these other soil functions is vital for maintaining future food output.

Today's circular economy (CE) concept rejects the specific aspects of economic growth (e.g., mass production, consumption of scarce and non-renewable resources, generating non-durable goods, etc.) and proposes fresh ideas for preserving natural capital and enriching social security. the compelling reason is to achieve the lowest possible material and energy stream across economic processes and prevent resource leakages (MacArthur, 2013). Unlike earlier sustainability endeavors, these efforts receive heightened attention from the corporate sector. Consistent with Edgerton (2017), the World Business Council for Sustainable Development (WBCSD) study, 80% of the surveyed businesses emphasized the rapid development and the augmentation of rivalries as drivers to adapt circular strategies. the remaining 20% suggested risk mitigation as a principal reason to expand a circular business model (WBCSD, 2017). However, it is implicit that the CE has also influenced the business model research. in framing the concept of circular business models, Scott (2013) contends that such initiatives must either use renewable biological materials or recycle their technical materials. Both of these activities do not harm the environment. Unsurprisingly, Mentink (2014) asserts that circular businesses must generate and acquire value within closed material loops. However, the business model singly cannot be circular but instead can be realized through a shared business nexus. Further, Bocken, Rana, and Short (2015) categorize circular businesses based on environmental strategies. They discovered that companies might impact resource loops in three distinct ways. the primary way is to reduce resource flows by extending product use which necessitates the design of durable equipment. Secondly, the closure of loops through recycling materials implies the diminution of resource consumption. Systematically, Lewandowski (2016) acknowledges businesses as circular if their model includes essential CE characteristics (e.g., resource optimization, loop closure, etc.).

In Singapore, the local farms are encouraged to seek out novelties in food production to elevate Singapore's limited food production amid contentious necessities for land, energy, water, and labor. for instance, indoor multi-tier farming mechanization and site-specific crop management (SSCM) through sensors and the Internet of Things (IoT). in challenging times, Singapore unveiled the "Farm Transformation Map" in 2017 that drives sector revolution and partnered with domestic producers to employ intelligent technologies and innovations to boost space usage and increase productivity. This would mean those producers can cultivate more with less simply by reducing dependence on labor and alleviating ecological consequences. Thus far, a number of the high-tech farms consume 70% less water and 50% less work at the same time as producing around six times the average quantity of vegetables and fish. the Singapore government offers technical assistance vis-à-vis training and R&D to farmers and set aside a war chest of S$63 million Agriculture Productivity Fund (APF) to encourage additional farmers to invest in productive technologies and transform the agriculture sector. It is pertinent to note that the Agri-Food and Veterinary Authority of Singapore (AVA) collaborates with tertiary and research institutes to support Singapore farmers.

B. Emerging Strategies Toward Adaptation to Climate Change

Rapid urbanization and industrialization on a global scale have worsened the effect of climate change, endangering the farming and food production sectors. the fluctuations in the frequency and severity of droughts and floods may present challenges for farmers in maintaining

their crop yields. Yet still, the hotter sea waters can disturb ecosystems, jeopardizing fishery supplies.

Climate change can create melting of the icebergs at the Poles with rising tides and higher water levels with soil erosions and land scars and the coastal areas and sinking of some islands around the globe. the rise will likely be a one-meter sea-level rise by 2100 (the Straits Times, 2021). If all of Greenland's ice melts, the global mean sea level could rise to over seven meters (the Straits Times, 2021). When the ice melts, this gravitational pull to the poles declines, and more water is drawn to the Equator in its place. At the Equator, Singapore could get about 30 percent more water than the rest of the world (Horton cited in the Straits Times, 2021).

Can we minimize the rate of rising? to also fight against the rising water levels (and soil erosion) due to global warming, shoring and propping the coastline with seawalls and sandbags are particularly common, especially in the South Pacific islands such as Tuvalu. and in Kiribati, the Ministry of Foreign Affairs and Trade (MFAT) commenced consulting on potential land reclamation at Temaiku in 2015 and 2016. Further, it commissioned the National Institute of Water & Atmospheric Research Ltd (NIWA) to consider coastal inundation and defenses in Kiribati in the broader context of global climate change. in 2017 Jacobs was engaged to conduct a detailed investigation of one site on the atoll of Tarawa and to provide a full feasibility report. [That report was presented in late 2018; it would have created a village sitting 2 meters above the projected 2200 sea level, hopefully buying 35,000 i-Kiribati another couple of hundred years in their homeland.] (Low, 2019, p. 65).

Singapore's current efforts to protect its coastal areas from erosion include the construction of walls and stone embankments covering 70 percent to 80 percent of its shoreline. the remaining are typical zones, for instance, seashore and tidal forest (or mangrove swamps). Notwithstanding the planning, design, and construction of works directed at land reclamation from the sea, countering subsidence, preserving coastal areas, assisting navigation, and providing anchorages are decisive mitigating factors. in addition, the island republic's local institutions have collected and shared interest in natural shoreline preservation, such as plants like mangroves and seagrasses as natural barriers to inundation or flooding.

Next, to be sustainable in the light of climate change, the public (directed or influenced by leaders or government) too should change their mindsets, adopting "mind growth" (Low, 2012; un-trapped mind and self-cultivating) and being involved. in essence, it is to make Singaporeans appreciate and value nature and sustainable development, similar to the saying, "If you want to hear the sound of the bird, don't buy a cage. Plant a tree." Such a strategy is to tap Singaporeans' high literacy rate or level. They need to be aware of minimizing food wastage, using food waste to create compost, mulching, and building eco-gardens. the public should take care of the environment and create a kind garden for the planet and wildlife. and more so, they are equipped and have the know-how. the public is acutely aware of the importance of the necessity to collect/reduce/recycle the use of water. How to plant the gardens with trees, shrubs, flowers, and food crops to help mitigate the effects of climate change, capture air pollutants, and create habitats for a vast number of creatures. Organic growing methods and a water source keep wildlife thriving, while selecting furniture and equipment made from sustainable materials will help lower the country's carbon footprints.

Remarkably, many plants will assist in sustaining wildlife in the individual gardens within each country. Seeds, berries, fruits, and nuts are essential food sources for birds and other small creatures, while trees supply nesting and roosting sites for birds. Flowers attract bees and insects that are, in turn, a vital source of protein for young birds and mammals. Here, the country's education system can play an integral part, and National Libraries, becoming learning and applications oasis, can also stock such books and records as well as those on water/waste management/nature conservation and sustainable development for the public consumption. Gardening clubs and societies are also formed in schools, heartlands, and community centers to effectuate these public mind-growths.

Countries can also adapt technology (for example, various desalination methods to derive pure water from seawater or turn deserts into arable lands) to adapt to climate change (food/energy production/water resource and waste management, and sustainability). Indeed, innovation and technology can enable Singapore farmers to grow more with less, be more resource-efficient, and reduce exposure to environmental risks. Hence, building a progressive farm sector will also entice a new generation of agri-specialists and expand regional food security efforts.

C. Tenets of Sustainable Adaptation

As Singapore imports almost all of its food, it is paramount to continue diversifying the import sources. There is a constant supply of commonly-consumed food items while providing buffers from external price shocks. Furthermore, the government needs to teach the values of sustainable consumption and prevention of food wastage in the populace. This includes utilizing institutional knowledge on preventing food wastage and educating young people on prudent food consumption practices.

The authors take the view that sustainability comprises three pillars that is economy (profits), society (people), and the environment (planet). and all three would benefit from these tenets of sustainable adaptation. of prime importance, the leaders, who walk their talk, need to set the example with the populace and the business people taking a stance of unlearning, co-learning, relearning (Dutta 2019), accepting the sustainability measures as necessary and vital.

Collaborative – win-win – efforts of the government, industry, and public are also needed. More critically, governments should lead or initiate steps towards sustainable growth. in so doing, we first position corporate involvement from the perspective of corporate social responsibility and corporate social responsibility communication vis-à-vis the relationship between talk and action and the potential of conversation in leading to action. Finally, the authors propose a conceptual framework that theorizes talk (word) and action (move/effort) as functioning collectively based on this.

To find meaningful connections between learning, adaptation, and practice, Stelmach invites us to integrate data-gathering methodologies with collaborative techniques for interpreting evidence into knowledge that impacts program practice and government policy (Stelmach, R., Fitch, E., Chen, M., Meekins, M., Flueckiger, R., Colaço, R., 2021). in galvanizing internal resources, the same authors identified the so-called MERLA (monitoring, evaluation, research, learning, and adapting) framework as its parts' integrated and complementary nature. the separation from the traditional siloed nature of M&E (monitoring and evaluation) instead challenges programs to connect data collection directly to learning needs and work with various stakeholders to make meaningful changes according to their findings. Across iterative learning and continuous adaptation, the MERLA framework improves flexibility, effectiveness, and evidence-based programs owned and led by local stakeholders and collaborators (Stelmach et al., 2021). to this end, Singapore (Singapore Green Plan, 2022) is looking at ways to raise trips taken on mass public transport from 64 percent to 75 percent by 2030.

Meanwhile, to be green and sustainable, Singaporeans are encouraged to do walking, cycling, and active mobility; and the island Republic is expanding its cycling network from 460 km. to around 1,320 km. by then. Note that such habits will need time to set in in society. and that is why the education system is teaching the young early. the education includes such programs as our Eco Stewardship Program, which involves students from Primary to Pre-University levels to understand sustainability and climate change; while feeling empowered to minimize their carbon footprint, ensure accountability, and influence their families and friends.

The Chinese saying, “Preserve the old but know the new,” is apt here. the old here refers to nature, human needs for survival, and farming. and knowing and applying what is new, that is, technology (a means of boosting productivity/output, reducing wastage, and raising profits), is the key here; it is also another fundamental tenet of sustainable adaptation. Technology, for example, is also being used to boost the quantity and quality of Singapore-produced fish. for example, some coastal fish farms have begun using closed containment systems for farming fish in controlled environments. This protects the fish from external elements such as rising sea temperature, algae blooms, and oil spills, which can wipe out tons of fish (creating losses and wastage). Notably, the fish in closed containment systems are farmed in contamination-free environments, and consumers can be sure that the fish are safe to eat.

D. Bridging Collective Actions: Concept of the Food, Water, and Energy Nexus

Water has always been an existential problem for Singapore. Singapore is categorized as being water-scarce and as the most water-stressed nation in the world, according to the World Resources Institute's 2015 report. Singapore also ranks 170th out of 190 countries in respect of freshwater availability. Accordingly, Singapore's limited natural supply of freshwater is aggravated by the small land area, severely restricting the space to capture and store rainwater.

Often, there are collective or collaborative efforts of the Government, industry, firms (farms), and the public (SFA, 2020). These include the Government's assistance in jump-starting the growth of the farms and the giving of grants for better or advanced technology (food, water, and energy) applications. Government agencies such as Jurong Town Corporation (JTC), Housing and Development Board (HDB) also work together to identify or find alternative farming spaces, such as industrial areas and vacant sites that can be transformed into food production facilities (SFA, 2020). for example, since May 2020, SFA has offered tenders of HDB multi-story car parks for rooftop urban farming.

Moreover, the government has also encouraged consumers to support the island Republic's farmers by choosing local produce. Their spending choices contribute directly to the local farmers' commercial viability and the country's food security (SFA, 2020). Unsurprisingly, SFA (2020) partners with grocery retailers to raise awareness of local produce through joint promotions and in-store messages. Beyond presence in brick-and-mortar stores, consumers can also place online orders for local produce through the Lazada Redmart website/mobile app.

IV. DEFINING KEY CHALLENGES OF FOOD, WATER, AND ENERGY SECURITY AND ADAPTATION TO CLIMATE CHANGE IN SINGAPORE

Singapore, 719 sq. km, has a limited land area; it has no mountains or rivers to tap, wind, hydroelectricity, or solar energies. Water, a scarce resource, needs to be conserved and well-managed. Climate change can affect the countries’ water supply, as increasing rainfall intensity (monsoons, storms, etc.) could engulf their drainage systems and create flooding. At the same time, dry weather (drought, hot spells, etc.) will reduce local catchment water availability for supply. and Singapore is indeed not exempted from this. Controls of floods and ponding prevention are also implemented through underground canals/reservoirs and the Marina Barrage systems.

Nonetheless, as an island Republic with an extremely limited water supply, taking suitable measures to safeguard the sustainability of its water resources is a top priority for Public Utilities Board (PUB), Singapore's National Water Agency. PUB has established the following Four National Taps to address its water needs:

- Local catchment water
- Imported water
- NEWater - the NEWater process recycles Singapore's treated used water into ultra-clean, high-grade reclaimed water, cushioning its water supply against dry weather and moving Singapore towards water sustainability. the NEWater process recycles the country's treated used water into ultra-clean, high-grade reclaimed water, cushioning its water supply against dry weather and moving Singapore towards water sustainability.
- Desalinated water (NCCS, 2022; PUB, 2022).

Interestingly, important in this Water Resource Management [WRM; NCCS, 2022], NEWater and desalination are not contingent on rainfall. Instead, they have become increasingly essential water sources to bolster Singapore's water security, notwithstanding climate change.

A. Increasing Population and Declining Agricultural Land

Despite land reclamations, Singapore has a limited land area indeed. She also faces population growth (SFA, 2020), which may strain or stress her resources and land for housing, food production, and aquaculture.

Arguably Singapore, with a total land area of 710 square km and inhabitants of 5 million, is one of the world's most densely populated cities. with most of the island's land used for urban development, the remaining 250 acres of farmland are barely sufficient to feed the growing population. Therefore, to maximize the land used for food production in Singapore, where land lot price is luxurious and ultraexpensive, the only feasible alternative left is to go vertical to make the island more self-sufficient in food.

"A-Go-Gro" Technology (Krishnamurthy, 2014) has been adopted, and it is the world's first low carbon hydraulic water-driven vertical system in growing tropical vegetables vertically in the tropics. and this gives significant yield and uses less water, energy, and natural resources to achieve a sustainable green high-tech farm. Remarkably, the vertical farming (VF) system grows vegetables in A-shaped towers, each six meters tall (see figure 1). These modular A-frames are fast to deploy, and the maintenance is uncomplicated. Each tower incorporates 22 to 26 tiers of growing troughs, which are rotated around the aluminium tower frame at a rate of 1mm per second to enable consistent dispensation of sunlight, good airflow, and irrigation system for all the plants. It is said that the plants do not get overstressed under the sun, and together, they can get nutrients in the water equally (Krishnamurhy, 2014).

Fig. 1 A Sky Green farm tower

Photo credit: Kalinga Seneviratne/IPS.

Singaporeans are also encouraged to grow their vegetables. They are also urged to grow more in a small space (strategies for growing food in the city), such as expanding on a balcony and growing food plants in the shade while maximizing production.

B. Declining Food Production

Declining food production is a perennial or continuing issue, if not a problem. and raising productivity is indeed vital to reducing the decline in food production. Singapore should increase its local production with an ambitious '30×30' goal to game-change food security. with COVID-19 further enlarging this need, Singapore Food Agency: SFA launched an "express" grant to push the industry into accelerated mode. Singapore needs to increase local production with an ambitious '30×30' goal to game-change food security (see Figure 2). with COVID-19 further magnifying this need, SFA launched an "express" grant to jump-start the industry into an accelerated mode (SFA, 2020). to safeguard and secure a supply of safe food for Singapore, SFA adopts the three (3) main strategies:

a) Diversify import sources - Singapore imports more than 90 percent of its food from about 170 countries and regions (SFA, 2020). This source diversification strategy has served the island-Republic well over the years, helping it weather through short-term disruptions that have intermittently arisen from supply shortages overseas now and then.
b) Grow local with '30x30' goal – the recipients of the 30×30 Express Grant will be given a shot in the arm to:

1. defray the upfront costs needed to expand farm production capacity within the next 6 to 24 months.
2. co-fund productivity-enhancing technology systems.

The plan is for the island Republic's food production to raise its resilience against climate change, resource constraints, and economic pressures. These farms must leverage science, technology, and innovation as enablers to attain these three types of resilience (SFA, 2020).

Fig. 2 A Sky Green farm tower

Photo credit: Kalinga Seneviratne/IPS.

Singapore operates towards its 30 by 30 goal of developing the agri-food industry's capability and capacity to sustainably produce 30 percent of its nutritional needs locally by 2030. Aquaculture, too, has a big part to play. After all, fish is a commonly eaten source of protein that can be farmed locally, productively, and sustainably, thus reducing the Republic's reliance on imports and strengthening its food security (Gomes and Domingos, 2022). It is evident that managing a successful fish farm begins with having a solid foundation, that is, growing healthy fingerlings. Indeed, healthy fingerlings have an increased chance of developing into sturdy fish (Gomes and Domingos, 2022).

3. Grow overseas (SFA, 2020; YouTube: How Singapore does farming without farmland https://www.youtube.com/watch?v=vjG8M1b-bN4www.youtube.com/watch?v=vjG8M1b-bN4www.youtube.com/watch?v=vjG8M1b-bN4) Singapore also run farms in several countries such as in Malaysia and in other countries.

B. Rising Water- and Energy-Intensive Food Production in the Face of Water and Energy Scarcity

In terms of resources, more Singaporean farmers are starting to adopt space-efficient and environmentally sustainable practices such as indoor farming and vertical farming. Resource-saving LED technology and solar panels are also rising (SFA, 2020). However, as more fish

are kept at a higher density in aquaculture, the water quality might decline with unconsumed fish feed and waste. This affects the health of the fish. However, it can also undesirably impact the surrounding environment, resulting in deteriorating natural habitats such as coral reefs and the seabed. Upkeeping ideal water conditions is thus essential when it comes to sustainably produce more fish to achieve the island's food security goals in light of water and energy scarcity (Gomes and Domingos, 2022). Here, one can immediately notice the connections between water cleanliness or quality, food production, energy, and ecosystems. Dirty or unpolluted water will kill the fish or affect the growth of the fish fries. Furthermore, the water quality can be monitored by farmers conducting regular monitoring (Gomes and Domingos, 2022) – consequently, be able to pick up changes such as increased ammonia levels or a drop in oxygen levels to breed big, healthy fish.

Of strategic interest, Singapore Aquaculture Technologies' Smart Floating Fish Farm is also applying artificial intelligence (AI) to track its fish's health and growth rates. At the same time, the Aquaculture Centre of Excellence's Eco-Ark is using its patented technology to produce more fish with less energy and cleaner water (SAFEF, 2020). in ensuring sustainability in aquaculture, data from monitoring water quality and aquaculture activities can assist farmers farm more innovatively, avert and managing the spread of diseases, feed their fish better, and improve the fish's yield and survival rate (Gomes and Domingos, 2022). Taken together and equally critical, such helpful aquaculture practices can help certify that Singapore's surrounding waters are not degraded over time, therefore safeguarding the sustainability of aquaculture. to be sustainable, farmers need to be conscious of the farm's impact on the environment and vice versa.

Countries such as Singapore lack resources, making them so vulnerable. It is said that Singapore's existence is by miracles, especially in such times like the present Covid 19 pandemic era (SFA, 2020). "It is a big challenge, as we are aiming to meet these (food production) needs using less than 1 percent of our land area in Singapore; (and this is) "the most ambitious" (Minister for Environment and Water Resources, Masagos Zulkifli was cited, SFA, 2020).

Singapore's population, especially the elderlies and the seniors, are somehow not so open and/or flexible enough to readily accept such sustainability measures. Here, the saving grace of the populace is that, however, the younger generations are more open and are educated in the Singapore education system to accept these sustainability measures as ("must be embraced") given formulas in life. Besides, the Republic's Ministry of Education continues to enhance sustainability education in the curriculum, especially among the young (Mothership, 2021).

V. RESULTS AND DISCUSSIONS

Based on the circular features in WEF business models, Table 4 encapsulates their evaluation according to the ReSOLVE criteria. the initial observation is the complete absence of "regeneration" characteristics. Or at least it is not exemplified in the characteristics of the mainstream ones. Conversely, "sharing" and "Optimize" are widely held pattern. and this can be traced back from the small-scale models lease technology platforms or other services. Another explanation for "optimization" being commonly adopted in MNCs can be attributed to the attractive compromise between the appearance of sharing and optimization. There is either the MNCs justifying its processes via outsourcing or SMEs providing platforms for that. the general application of sharing and optimization occurs only if there is at least one more circular feature in the model.

Table 4. The evaluation of circularity criteria in WEF business models

Business model	Regenerate	Sharing	Optimize	Loop	Virtualize	Exchange
Open Innovation based R&D			Yes			
Networked			Yes			
SQA excellence			Yes			
Fully diversified						
IP-oriented		Yes				
Repurposing and technology brokering		Yes		Yes		
the distributed partnering				Yes		
Outcome-driven		Yes				
Bundling					Yes	
Crowdsourcing			Yes		Yes	
Virtual collaboration		Yes	Yes			
Software as a Service		Yes	Yes			

Notes: Yes - indicates which ReSOLVE element appears in the certain business model.

The feature that results in the various application of circular components is 'virtualization'. the utilization of digital tools is a distinctive attribute that applies only to data-driven open models. for example, it happens as virtual platforms for partnership, managing data, outsourcing tasks, and a conduit for advisory services. Virtualization also permits material optimization for small R&D companies already working on a low resource intensity. Finally, thanks to the impending digital revolution, this attribute will be a fundamental requirement in CE and general business (Fleisch, Weinberger, & Wortmann, 2015).

A. Clean technology Needs to be Tapped

Regarding the body of research on VF, it is pertinent to highlight the role of greenhouses in conserving and reusing energy (Specht et al., 2014); for instance, the system which utilizes natural light, artificial light, and energy to enable the environment management (temperature control), water supply (irrigation) and nutrient delivery (Perez, 2014; Sivamani, Bae, Shin, Park, & Cho, 2014).

Climate change, fossil fuel depletion, and rapid urbanization drive countries to deploy cleaner and more sustainable energy solutions. the lighting challenges can be daunting: over two-thirds of the worldwide energy is guzzled in cities. A significant point and a drawback frequently underscored by the adversaries of VF is how plants that grow inside a building have sufficient energy required for plant growth (Al-Chalabi, 2015; Specht et al., 2014). While vertical farms located inside buildings get less access to natural light, this necessitates the demand for artificial lighting frequently supplied by LEDs, which is analogous to greenhouse farming. However, this additional cost must be taken into account (Banerjee & Adenaeuer, 2014).

Further, as postulated by Perez (2014), if the agriculture industry of the US observed a VF approach, then the electricity consumption for lighting is going to be eight times that of the amount generated by all power plants annually in the US. in reality, making full use of additional lighting in VF continues to be a challenge. and Singapore has acknowledged the clean energy industry as a strategic growth area and has employed a comprehensive blueprint to develop this industry (NCCS, 2022). True, climate change poses significant global challenges; it can also provide strong incentives for entrepreneurship, research and development (R&D), and creative problem-solving to help cities and communities anticipate, prepare for and adapt to its impact. As far as the environmental advantages, VF in cities protects biodiversity, minimizes wastage and loss, and limits the energy used for generating and supporting sustenance to the public (Thomaier, S., Specht, K., Henckel, D., Dierich, A., Siebert, R., Freisinger, U. B., & Sawicka, M., (2015), nevertheless, VF is not a universal remedy for all current sustainability difficulties but it can contribute considerably by resolving existing problems. It can replace industrial agriculture and be a better substitute by curtailing damages triggered by traditional open-field agriculture. Therefore, VF offers many ecological benefits and can pivot agriculture toward agroecology. As a result, Singapore can develop as a green growth hub that provides green solutions to the world. Here, it is said that within the clean technology (cleantech) sector, the island Republic has obtained several critical investments in high-value manufacturing, engineering, biofuels, research and development (R&D), and regional headquarters activities (RD).

Singapore has a close relationship with the international community and collaborates to share technical experience and best practices. in addition, Singapore is committed to being a constructive and active actor in discussions on sustainable energy at multilateral opportunities such as ASEAN, APEC, and G20, as well as through engagement with international organizations, for example, the International Energy Agency (IEA) and International Renewable Energy Agency (IRENA).

B. Prospects of Water Demand with Recycling

The world is convinced that industrial farming will produce an abundance of food. Perez (2014) concludes that the deciding aspect that allows the implementation of VF is the water supply (Perez 2014). VF is not a unique application for manufacturing food, but it can help recycle Singapore's water supplies. Notwithstanding these limitations, Singapore is well advanced in attaining universal access to cheap (affordable) and high-quality water, including modern and available sanitation for every citizen. Its policies are driven by enduring planning, bolstered by the desire to achieve water sustainability to support the population and economic developments. Singapore has embraced an integrated closed-loop approach to water management to realize this.

PUB (Singapore's national water authority) aims to optimize Singapore's water resources by incorporating water supply, sewerage, and drainage functions in managing the entire water cycle while exploiting opportunities for water reuse through wastewater reclamation technologies and innovation. Here the approach to water management is driven by three key strategies:

- increasing the yield by storing every drop of rainfall in Singapore;
- producing water, an incessantly reusable resource by recycling and reusing wastewater; and
- transforming sea water into drinking water through desalination. This will guarantee that not a single drop of water will be wasted. Additionally, a strong emphasis on technology and innovation undergirds the water management endeavors via capitalizing on R&D and experimenting with new technologies.

Notably, NEWater (Singapore's brand of ultra-clean, high-grade reclaimed water) is supplied by employing advanced membrane technologies and ultraviolet disinfection to disinfect treated wastewater. Attributable to

its ultra-clean nature, NEWater is well regarded by the industry and is mainly supplied to non-domestic sectors such as wafer fabrication parks, industrial estates, and commercial buildings for industrial and cooling purposes. Through the dry season (mid-year), the NEWater can be added to the local reservoirs to expand drinking water supplies.

Desalination too is a feasible alternative for supplying fresh water, with the advancement in membrane technology, it has lowered the cost of desalination considerably. Presently, Singapore has three desalination plants with a combined total capacity of 130 million imperial gallons per day (mgd).

C. Ensure sustainable consumption and production patterns

As argued previously, Singapore is impeded by its limited resources and land scarcity. So, to provide a secure living ecosystem with a high quality of life for present and future generations, Singapore's attempt at sustainable consumption and production is becoming a Zero Waste Nation. Energy and raw materials are used to produce and get goods to consumers. Therefore, it is existential to safeguard resources in obtaining greater value from waste as a resource. in the same way that Singapore has effectively closed the water loop through continually recycling water, Singapore also endeavors to close the waste loop via a circular economy. This can be undertaken by applying the 3Rs: Reducing, Reusing, and Recycling. As a result of reducing waste and consuming materials and goods, Singapore can steer clear of draining the planet's resources through careless habits. This keeps Singapore clean, safeguards precious resources, and minimizes the necessity for space-consuming landfills. the Zero Waste Nation attitude is embedded into its national plans and policies, for example, the Sustainable Singapore Blueprint (n.d.). the Singapore government is actively working with industry stakeholders to integrate the 3Rs into business practices and, together with the public, to evangelize the message of responsible consumer behavior. and to seek to ensure that these efforts are in-line with international rules and standards on managing hazardous chemicals and wastes.

Small nation with little resources of their own, Singapore is reliant on imports to satisfy the consumer behavior, including food. Food movement in developing countries is unlike developed countries and so is the issue of food security. It is imperative that food waste reduction be managed.

In Singapore, the family unit and the industry each produce about half the amount of wasted food. Consequently, the government explored interesting initiatives to deal with the food waste issue. for example, they are persuading food manufacturers, retail grocery, and eateries outlets to discount or re-allocate unsold or excess food to consumers to donate to charities. Consumers are similarly urged to lessen food waste through marketing and advocacy initiatives that foster wise and sensible food purchases, preparation, and storing practices. Where food waste continues to be spawned, Singapore also established efforts to convert this waste into a resource. Encouraging on-site food waste treatment at business locations and public eating premises and conducting district-level food waste treatment invariably push up the food waste recycling rate.

There is indeed a need to boost or have more individual involvement in Singapore's green and sustainable mission/efforts and activities. These can include supporting local produce, changing personal habits, taking public transport, walking, cycling, leading an energy-efficient lifestyle, and starting a project using the Singapore Eco Fund (Singapore Green Plan, 2022). One can begin a Project using the SG Eco Fund – here, if one has an idea or project, one can apply for the SG Eco Fund as it offers financial support for ideas that can create a positive impact.

VI. CONCLUDING REMARKS

Environmental practitioners and scholars are considering trade-offs and collaborations that use a nexus approach to enable different adaptations towards climate changes and improve food, water, and energy security by exploiting its efficient usage and fostering greater policy coherence. the collective and shared desires of different actors can be used to guide the implementation of various adaptation possibilities to maximize gain, optimize trade-offs, and avoid negative impacts.

This study and the data review underlined the precedent and direction of WEF security in Singapore in identifying the key challenges to identify the main challenges and epitomize the prospects for future exploration and implementation of the WEF Nexus approach. in addition, ongoing developments mandate immediate attention to water, energy, and food security to achieve viable advancement in Singapore, where the economy is intensely reliant on commodities and food prices.

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CONFLICT OF INTEREST

The authors declare there is no conflict of interest.

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