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# Exploring the Commercialization of Smart Rural Energy in Times of Energy Supply Chain Disruptions

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**Abstract:** The lingering COVID-19 pandemic and ongoing war between Russia and Ukraine have wreaked havoc on the global oil supply chain. The current disruption of the oil supply chain and the rapidly growing energy demand created unprecedented oil shortages and raised the oil price beyond the affordable level. As worldwide oil price hikes continue, there is an urgent need for developing alternative energy sources, such as smart rural energy. Despite its enormous potential as a viable alternative to traditional fossil fuel-based energy sources, smart rural energy has never been fully utilized in society. The limited use of smart rural energy may be related to its lack of commercialization, which could have created more eco-friendly and cost-efficient alternative energy sources. This paper assesses the eco-friendliness and cost-efficiency of smart rural energy sources such as solar, wind, biomass, and hydropower for the first time. This paper is also one of the first studies that intends to develop viable strategic plans for commercializing smart rural energy using strategy maps, which subsequently helps increase public awareness of renewable energy by creating visual communication tools that convey the benefits of smart rural energy commercialization to multiple stakeholders, including government entities, business communities, and energy consumers.

**Keywords:** renewable energy; energy crisis; commercialization; strategy map; sustainability; global supply chain; balanced scorecard

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## 1. Introduction

The *International Energy Outlook 2016* (IEO2016) report forecasted significant growth in worldwide energy demand over the 28 year period from 2012 to 2040. Additionally, the total global energy consumption is expected to grow from 549 quadrillion British thermal units (Btu) in 2012 to 629 quadrillion Btu in 2020 to 815 quadrillion Btu in 2040—a 48% rise from 2012 to 2040 [1,2]. This rapid energy demand growth cannot be filled by traditional fossil fuels such as oil, natural gas, and coal. The rationale is that these conventional energy sources have been dwindling and have created adverse environmental conditions through pollution resulting from carbon emissions and natural habitat destructions during extraction. For example, the United States (U.S.) alone demands about 20.5 million barrels of petroleum fuels daily, of which about 68% is consumed by the transportation sector alone. The increasing use of these fuels will continue to increase air pollution, intensify global warming, and cause other environmental problems, including acid rain, by emitting various contaminants, such as $CO_2$, CO, SOx, NOx, and other volatile organic compounds (VOCs) [2–6]. To make it worse, their prices have been rising. For example, the oil price adjusted for inflation rose from $9.94 in 1931 to $80.70 per barrel as of April 2023 [2,7,8]. As such, a growing number of nations have started to recognize the urgent need for alternative energy sources.

Viable alternative energy sources include nuclear, solar, hydro, wind, wave, geothermal, and biomass. Except for nuclear, these alternative energy sources provide clean, non-toxic, and renewable energy, which is environment-friendly. Still, many of these sources have failed to completely replace fossil fuels (e.g., oil, natural gas) and satisfy growing energy demands, as shown in Figures 1 and 2. In particular, future energy demand in Asia is expected to double its market size from two decades ago due to Asia's explosive economic and population growth. Similarly, EIA (U.S. Energy Information Administration) predicted a nearly 50% increase in worldwide energy consumption by 2025, led by growth in Asia [9]. This energy shortfall will continue unless cleaner and more affordable alternative energy sources can be found and developed. That is to say, the best way to deal with the worldwide energy crisis is to create and commercialize more clean alternative energy sources. These sources seem to be smart rural energies that are easily accessible from existing natural resources and waste extracted from daily human/animal activities.

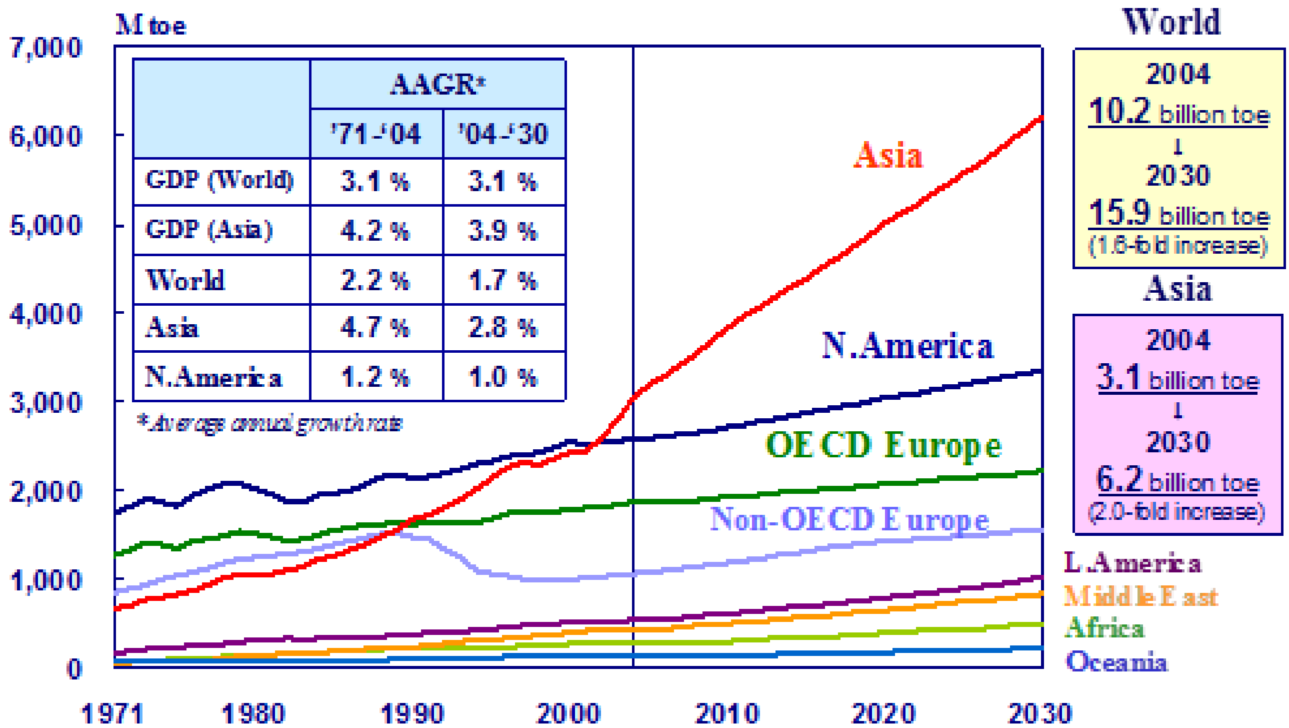


**Figure 1.** Worldwide energy demand trends. Data source: modified from Enerdata. *World Energy and Climate Statistics—Yearbook 2022*, https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html, accessed on 8 April 2023; OPEC, *Energy: Next Fifty Years*, unpublished report, 2019, OECD Publication Services, Paris, France.

Generally, smart rural energy is referred to as inexhaustible renewable energy (RE) generated from natural resources, such as sunlight, wind, flowing water, corn/sugar cane plants, and biomass abundantly available in rural areas that do not have substantial power grids. Despite the availability of these rich resources in rural areas, the rural community is often devoid of energy production and distribution/transmission capacity and thus rarely exploits smart rural energy (SRE). The limited utilization of SRE is attributed to the uniqueness and complexity of its supply chain (S.C.) process and a lack of infrastructure for SRE creation. For illustrative purposes, Figure 3 shows the typical biofuel S.C. process involving biodegradable materials that are considered one of the SRE sources. Another reason for the lack of utilization of SRE is the challenges associated with its commercialization, as noted in [6]. Considering the challenges associated with SRE generation, this paper aims to improve the SRE supply chain and commercialization processes by adopting a strategy map and balanced scorecard-based project monitoring tools. This paper's strategy map is designed to help SRE developers better understand its supply chain processes and succeed in commercializing SRE. With this in mind, this paper develops various scenario plans predicated on SRE supply chains and finetunes those chains to generate SRE on a large scale at an affordable price.

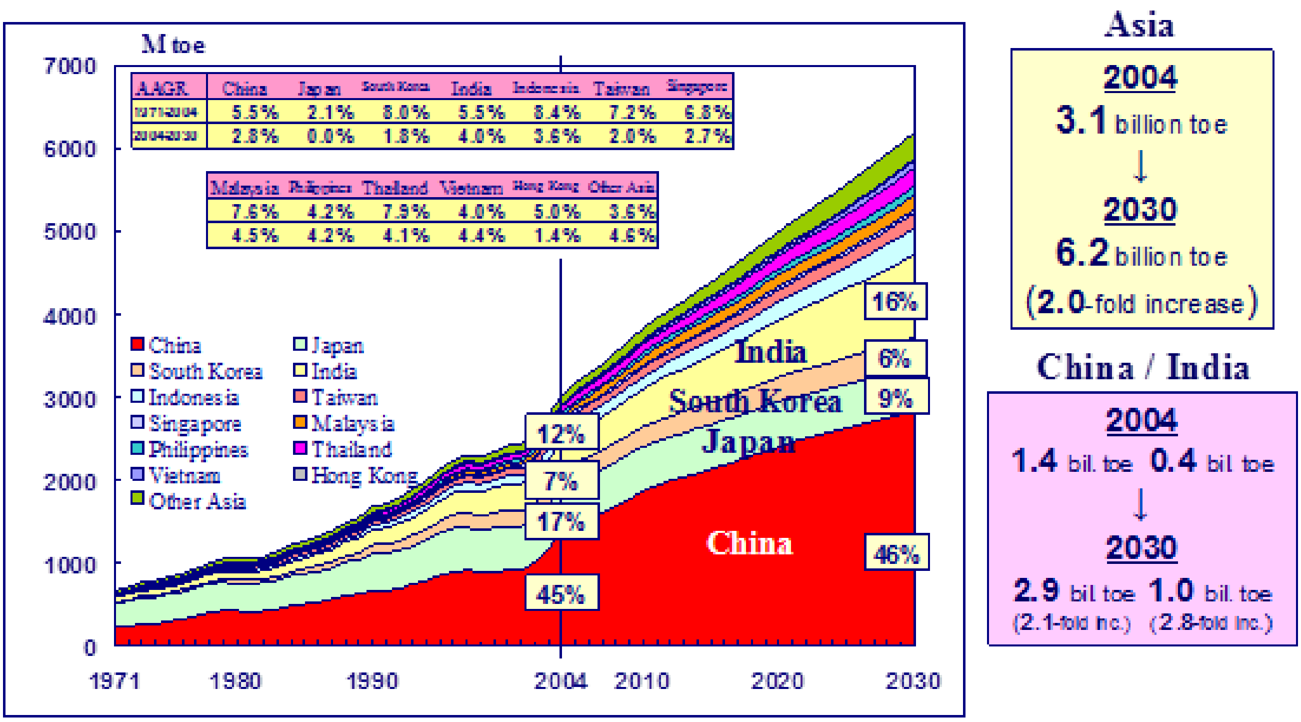


**Figure 2.** Energy demand trends in Asia. Data source: modified from Enerdata. *World Energy and Climate Statistics—Yearbook 2022*, https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html, accessed on 8 April 2023; OPEC, *Energy: Next Fifty Years*, unpublished report, 2019, OECD Publication Services, Paris, France.

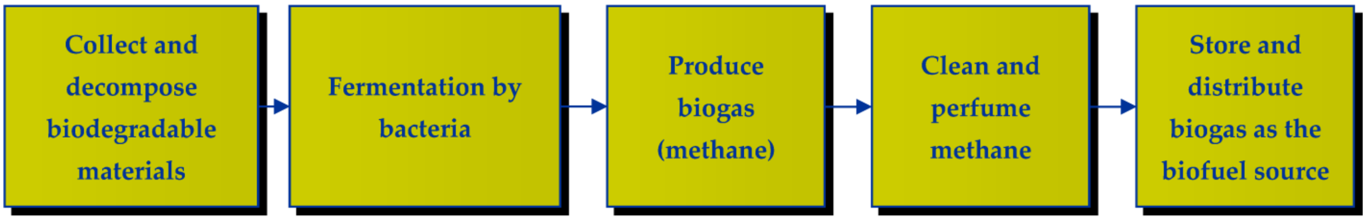


**Figure 3.** Typical biofuel supply chain process.

## 2. Literature Review

Fossil fuels account for over 80% of global energy consumption [10]. However, due to worldwide population growth and fast-rising energy demand, worldwide fossil fuel consumption is expected to peak in 2030 and begin to decline afterward [10,11]. As an alternative to depleting fossil fuels, RE has become a popular sustainable and environment-friendly energy source. Parallel with the popularity of RE, the literature dealing with RE-related issues has risen considerably over the last two decades [12–16]. Most of this existing literature focuses on the socio-economic, geopolitical, and environmental impacts, application areas, technological developments, demand projections, and investment ramifications of RE. In contrast, prior literature focusing on commercialization, business development, and S.C. management of RE is scarce. A few exceptions to this research trend include some pioneering studies, with examples including investigations conducted in [2,6,17–20].

To make sustainable energy (S.E.) available to local Indian communities that were deprived of traditional energy services, Balachandra et al. [17] explored several efficient ways to diffuse S.E. technologies to those communities in the long term. They observed that government initiatives primarily drove S.E. diffusion without much private sector participation. To encourage active private sector participation in large-scale, long-term S.E. technology diffusion, they explained what it would take to develop and diffuse S.E.

technology in India. Their study, however, was confined to the situation in the region of India. Similarly, Jagoda et al. [18] presented an innovation system framework for developing and diffusing RE technologies for small and medium enterprises (SMEs) in Canada. As an illustration of their framework, they conducted a case study of solar thermal system households in Calgary, Alberta, Canada. Their study was one of the few studies that discussed entrepreneurial activities/aspects related to the RE sector and analyzed business opportunities for SMEs in the RE sector. However, their study was limited to the diffusion of solar water heating technologies in Canada. Walsh [19] additionally developed a conceptual framework for determining appropriate RE commercialization strategies targeting SMEs. He also attempted to identify theoretical constraints for RE commercialization based on a comprehensive literature review dealing with technology innovation and commercialization strategies. He discovered that the commercialization of innovative RE technology was influenced by RE technology demand and eco-sophistication of the RE market.

Given that commercialization was essential to the successful diffusion of RE technology, Asiani [20] examined the role of RE technology commercialization in RE adaptation and identified the critical strategic variables involved in RE technology commercialization. These strategic variables that might hamper RE technology commercialization included budgetary limitations, end-user RE costs, a lack of understanding of RE markets due to instability, and inadequate government incentives for RE utilization. Based on a detailed case study of the biofuel industry, Lea et al. [6] presented data visualization techniques to create a positive image of biofuel production and improve the chance of commercialization success of algae-based biofuel businesses. They also developed specific performance metrics to gauge the commercialization potential of algae-based biofuel businesses from the balanced scorecard perspective. However, this study was confined to the biofuel business instead of broad RE business sectors. Furthermore, predicated on the theory of innovation, Haile and Min [2] assessed the impact of disruptive innovation on the commercialization success of RE businesses. The statistical analysis of data gathered from 204 policymakers of RE businesses across emerging economies found that disruptive innovation positively impacted RE market creation and helped enhance sustainable value. In other words, their study implied that disruptive innovation techniques, such as using new RE-generating technologies (e.g., artificial photosynthesis, 3D-printed solar energy trees, liquid sunlight), could increase the likelihood of RE commercialization success. From a slightly different angle from the aforementioned RE studies, Sala et al. [21] assessed the impact of RE investment and innovation processes on Ukraine's electricity sector in terms of economic, social, and environmental indicators. They found a correlation between the effectiveness of RE investment (including tax incentives, subsidies, and feed-in tariffs) and RE production capacity. They also underscored that the government policy encouraging RE investment is essential for accelerating the transition to a low-carbon economy and mitigating the impacts of climate change. Despite their unique contribution to the RE literature, their study was limited to Ukraine's regional situation and overlooked changing cost parameters in measuring the economic impact of RE investment.

As the literature above reveals, many research gaps must be filled. To elaborate, prior research up to this point focused on RE technology commercialization in developing countries and failed to formulate specific RE commercialization strategies or practical guidelines that can facilitate RE adaptation and diffusion across rural areas remotely located from the RE-powered electric grid system. More importantly, much of the existing RE literature rarely examined the role of the RE supply chain in RE adaptation, diffusion, and the subsequent RE demand creation that may contribute to RE commercialization success. To fill these gaps left by prior research, this paper proposes visual decision-aid tools, such as strategy and supply chain maps, while presenting the balanced scorecard (BSC) framework designed to gauge the commercialization potential of various SRE sources.

## 3. Research Methodology

Considering the paucity of SRE commercialization studies, this paper aims to address the following research questions.

(1) What are the key influencing factors for SRE commercialization success?
(2) How do we formulate business strategies that will lead to SRE commercialization success?
(3) How do we develop key performance indicators that help monitor SRE commercialization efforts and evaluate SRE commercialization success from multiple stakeholders' perspectives?

To answer the above questions, this paper employs multiple visual decision-aid tools to develop an SRE commercialization strategy, identify key influencing factors for successful SRE supply chain operations, and measure the extent of the impact of various SRE production and distribution alternatives on commercialization potentials. These tools are designed to present complex concepts in a graphical format and thus enable the decision-maker to grasp complicated and esoteric concepts more clearly [6].

### *3.1. Strategy Map*

A strategy map is a diagram that shows the organization's strategy on a single page [22]. It is useful for making the organization's strategic action plans transparent and communicating big-picture, long-term goals to every stakeholder in the organization in simple terms [23]. This map ensures that everyone in the organization is on the same page in pursuing the organization's long-term goals [6]. The strategy map for SRE commercialization is displayed in Figure 4.

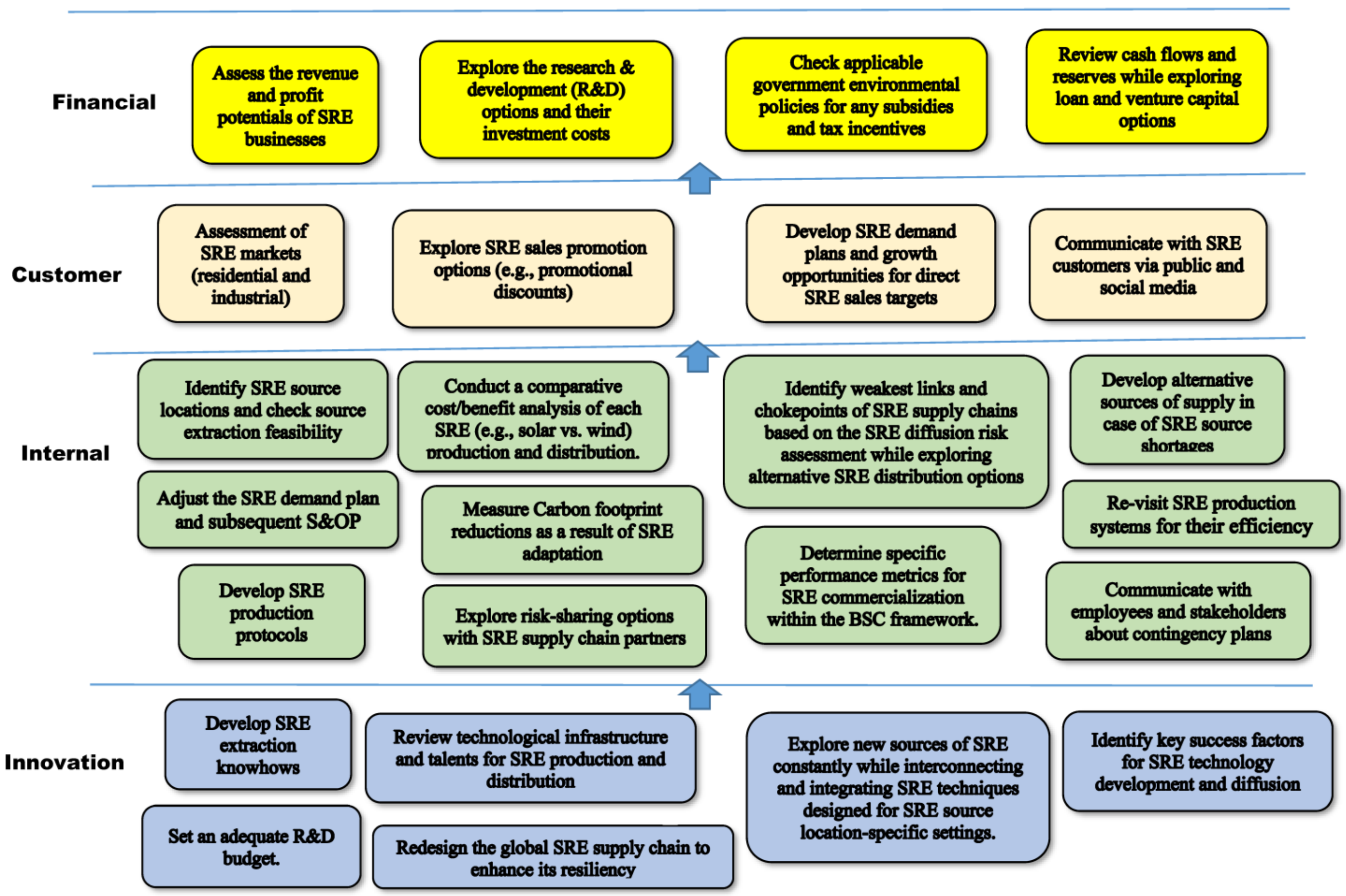


**Figure 4.** Strategy map for smart rural energy commercialization.

### *3.2. Smart Rural Energy Supply Chain Mapping*

As exemplified by the ongoing war between Russia and Ukraine, unexpected events, such as war, inclement weather, and accidents, can cause energy supply chain disruptions and hamper energy diffusion [24]. This kind of energy S.C. disruption can happen regardless of the type of energy source, including SRE. Since SRE S.C. disruption adversely influences SRE diffusion and the subsequent SRE commercialization, SRE businesses should be mindful of the potential barrier that SRE S.C. disruption creates. To complicate matters, SRE S.C. differs depending on the SRE source, as illustrated by Figures 5–7. To better handle SRE S.C. disruption challenges, SRE businesses need to identify the weakest link or the most vulnerable segment of the SRE S.C. With this in mind, this paper employs supply chain maps. A supply chain map is a graphical form of a communication device that helps decision or policymakers visualize information regarding SRE distribution dynamics, SRE diffusion flows, SRE infrastructure links, and SRE supply chain partnership connections [22,25,26]. For illustrative purposes, Figure 5 shows the wind energy S.C. map, Figure 6 shows the solar energy S.C. map, and Figure 7 shows the bioenergy S.C. map.

### *3.3. The Balanced Scorecard to Improve Smart Rural Energy Diffusion*

One of the visual decision-aid tools intended for performance evaluation and suitable for outcome assessment is BSC, introduced by Kaplan and Norton [27]. As shown in Figure 8, BSC measures business performance from four perspectives: financial, customers, internal business processes, and innovation and learning [26]. It also links the organization's operational plans and budgets and supports continuous performance monitoring and plan adjustments while ensuring that every decision-maker has the most up-to-date information and analyses at their fingertips [6,28]. BSC also focuses on the strategic aspect by charting the progress toward achieving long-term goals consistent with the organization's vision (e.g., creating cleaner environments, maximizing resource conservation, and improving SRE market penetration). Details of these perspectives are as follows.

#### 3.3.1. Financial Perspective

Each perspective of the BSC may have a different set of goals/objectives and performance measures. These goals and performance measures should be tailored to specific needs and surrounding SRE supply chain environments. Since the SRE commercialization success is tied to the SRE business's ability to maximize SRE sales revenue, throughput, market size (e.g., number of customers, including residential and industrial sectors), market share, and profitability, that ability should be monitored continuously. Thus, performance metrics, including key performance indicators (KPIs) relevant to SRE commercialization, must be developed based on that ability. Table 1 summarizes specific goals and performance metrics relevant to the SRE commercialization progress from the financial perspective.

#### 3.3.2. Internal Business Perspective

The internal business perspective investigates ways to identify SRE production and diffusion processes that are most critical for achieving SRE business stakeholders' (i.e., shareholders and customers) goals and focuses on monitoring those processes for their progress. This perspective also intends to identify the key parameters most important for competitive success. Furthermore, this perspective includes the social (community-wide) and environmental impacts of SRE investment due to the growing social responsibility of the energy industry [29]. Table 2 lists various goals and performance metrics from the internal business perspective.

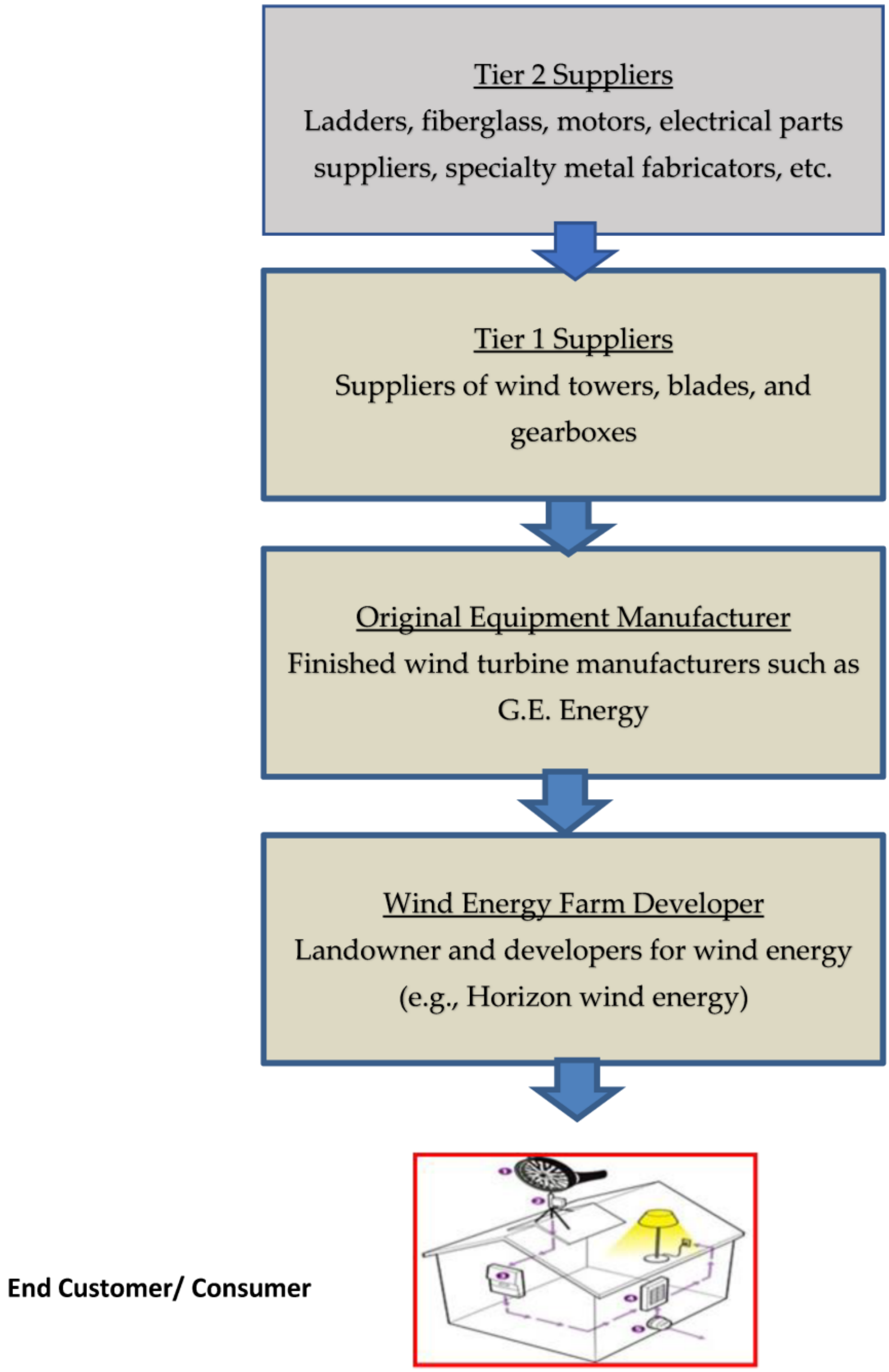


**Figure 5.** Wind energy supply chain map.

#### 3.3.3. Customer Perspective

High customer satisfaction can enhance the SRE business's brand recognition and the subsequent bottom line (e.g., profitability). Since customer satisfaction reflects the value created by the SRE business, this perspective mainly focuses on the SRE's ability to understand what SRE customers (e.g., utility users, municipal powerplants, vehicle users) actually want and deliver the customer value on time. Herein, the customer value includes positive images of SRE services and company goodwill (e.g., long-term commitment to sustainability). Since goals in this perspective can affect both the financial and the internal business process perspective, this perspective should take center stage for achieving the strategic objectives of SRE business commercialization success. For example, suppose automobile drivers switch to biofuel from traditional fossil fuels. In that case, they can save their annual fuel costs, reduce air pollution, and create healthier living environments. As such, these customers (automobile drivers) will be lured to use more SRE and will eventually help the SRE business generate more revenues. Likewise, the improved public image of the SRE business will increase its goodwill and help improve its revenue. Table 3 summarizes various goals and specific performance metrics (including KPIs) from the customer perspective.

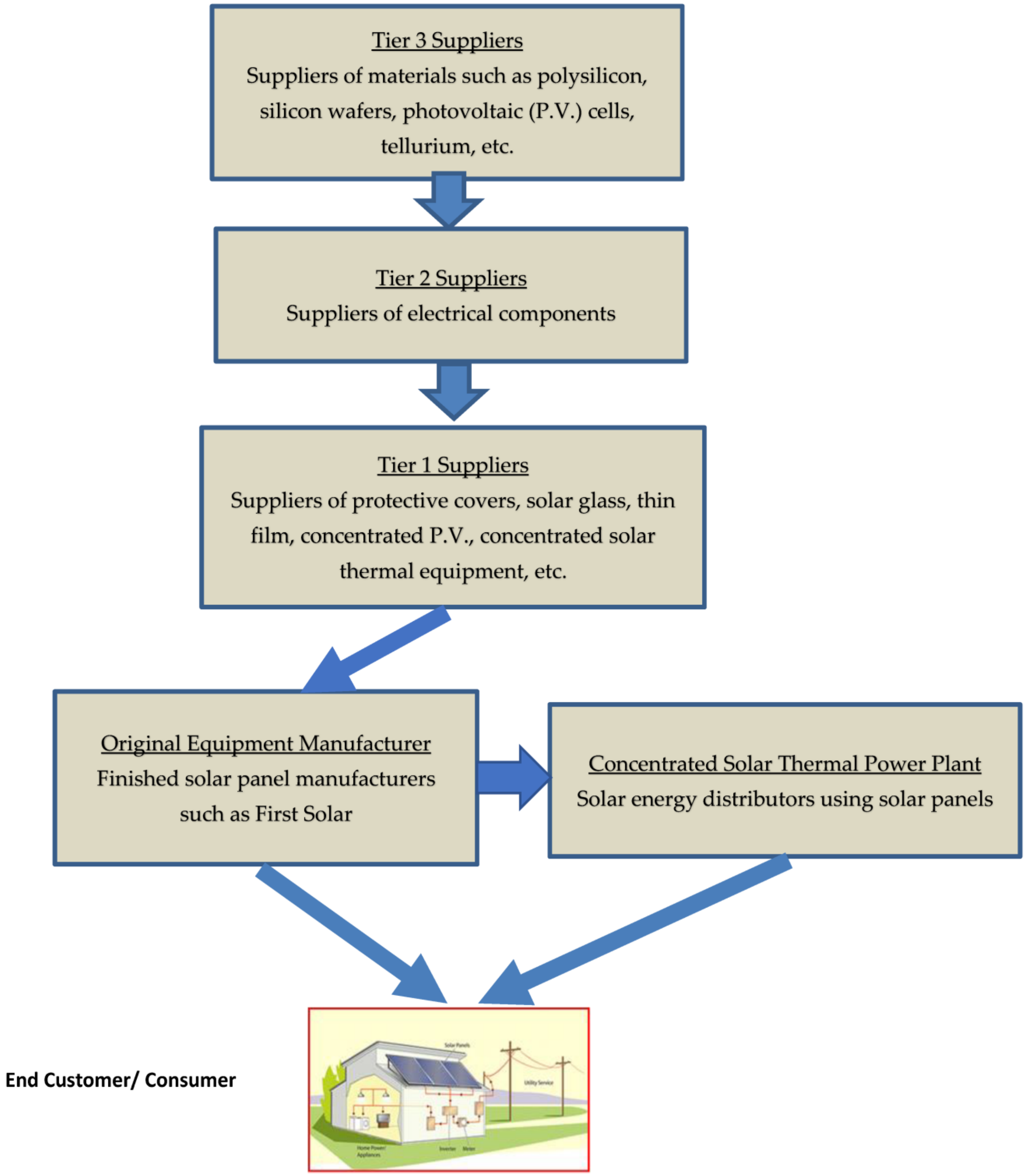


**Figure 6.** Solar energy supply chain map.

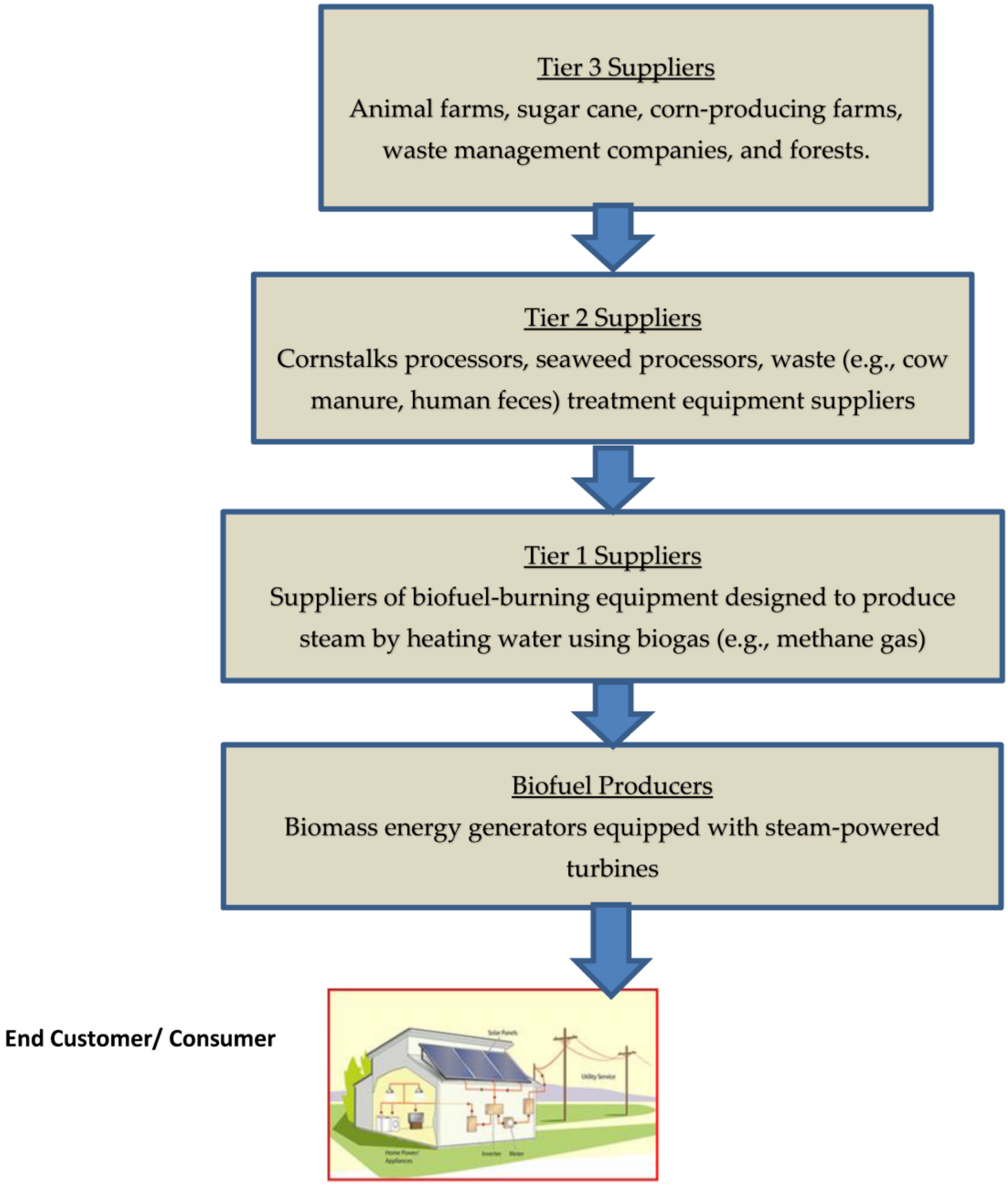


**Figure 7.** Bio energy supply chain map.

#### 3.3.4. Innovation and Learning Perspective

An SRE business's ability to innovate, learn, and improve continuously ties directly to its customer value creation. In other words, the SRE business's ability to continually launch new products and improve its supply chain efficiencies enables it to penetrate new SRE markets and increase sales revenues, thereby increasing shareholder value [26,27]. This perspective also deals with the SRE business employees' learning that helps hone employee skills/knowledge, which proves crucial for continuously improving SRE supply chain efficiencies and new SRE technologies. Table 4 recapitulated various goals and performance metrics from the innovation and learning perspective.

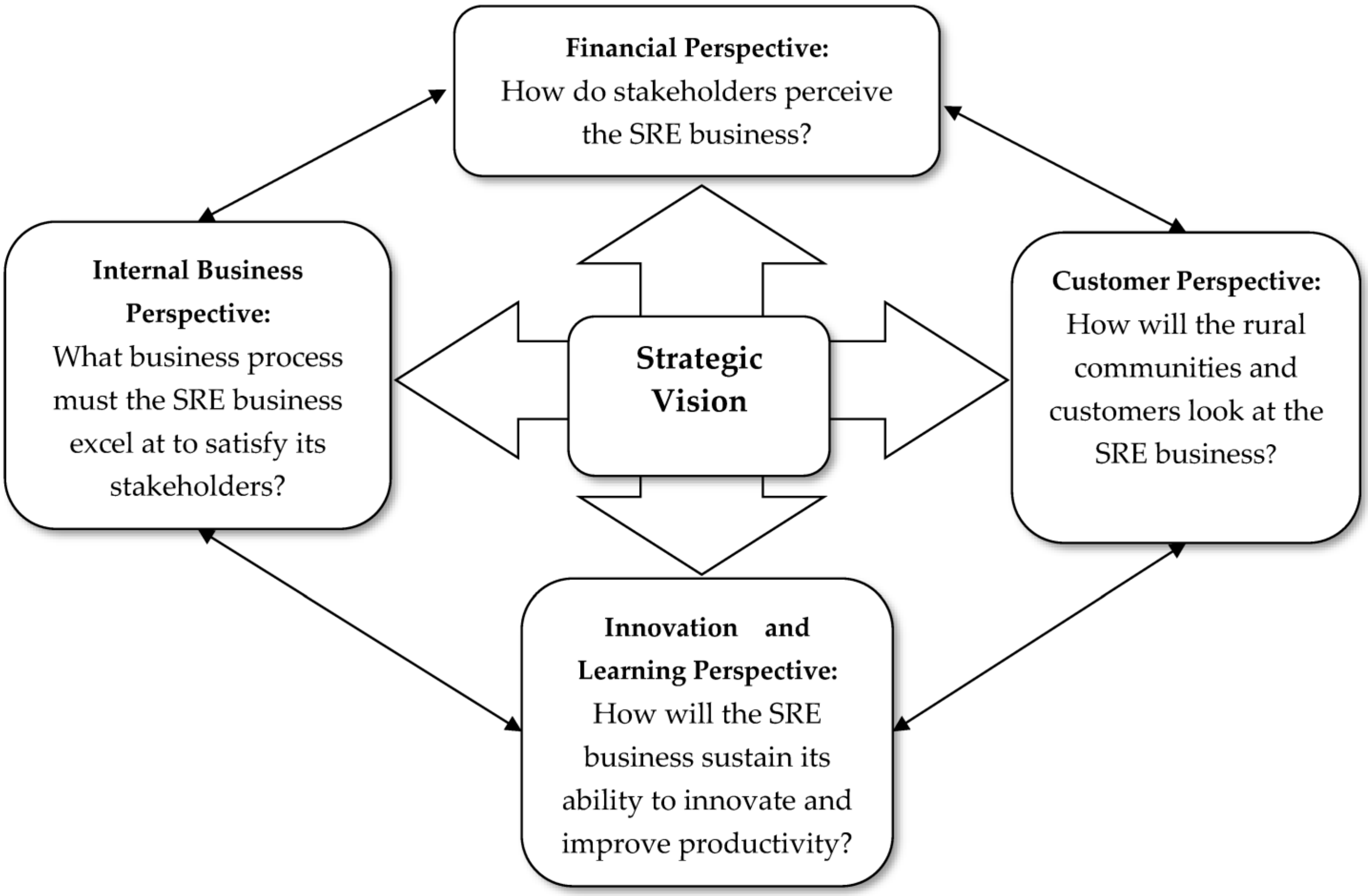


**Figure 8.** Balanced score framework for the SRE business.

**Table 1.** Financial perspective.

| **Goals** | **Performance Metrics** |
|---|---|
| Increase Throughputs | Yield volume = volume of SRE (e.g., biofuel) produced |
| | Accessibility to SRE sources (wind, solar, biomass, etc.) |
| Improve Profitability | Economic value added (EVA) = Net operating profit after taxes (NOPAT) − (cost of capital) |
| | Gross profit and profit margin |
| | Cash-to-cash cycle = days between the purchase of SRE source materials from their suppliers and payment collection for the sale of the SRE to SRE customers |
| | Cash flows = total cash inflows through SRE sales and diffusion − total cash outflows (e.g., cash expenses and taxes) |
| | Return on equity (ROE) = SRE business' annual return (net income)/SRE business shareholder's equity × 100% |
| | Return on investment (ROI) = (Profit/cost of investment in SRE development and diffusion) × 100% |
| | R&D budget (amount of funds available for SRE innovation) |
| | Asset turnover = Total sales volume/total assets used for SRE production |

**Table 1.** *Cont.*

| Goals | Performance Metrics |
| --- | --- |
| Increase Sales Revenue | The total volume of SRE sales and its by-products |
| | Annual or cumulative sales growth rate |
| Increase Market Share | Number of potential and existing SRE customers |
| | Diversity of SRE distribution channels |
| Increase Public SRE Acceptance Rate | Public's SRE acceptance rate |
| Capitalize Government Incentives | The total amount of government subsidies and tax benefits received |

**Table 2.** Internal business perspective.

| Goals | Performance Metrics |
| --- | --- |
| Improve SRE Production and Diffusion Efficiency | SRE cultivation efficiency = (Actual output quantity/Available capacity) $\times$ 100 |
| | SRE operating capacity (e.g., biomass harvest rate) |
| | Amount of electricity generation for heating and cooling |
| | Amount of fuel generated by SRE sources |
| | Annual SRE growth period = the total number of days the environmental (e.g., weather) factors were in favor of SRE source creation. |
| Improve the SRE Quality | ISO 50001 (healthy energy management system) and ECRE (IEC System for Certification to Standards relating to equipment for use in renewable energy applications) certification; meeting renewable energy portfolio standards (RPS) |
| Reduce Waste/Resources | ISO 14001 and ISO 20121 (sustainability event management) certification |
| Reduce Pollution | Water and air contamination rate |
| | The volume of air/water cleaned |
| Identify Core Competencies | SRE technology development efficiency (e.g., number of existing patents for SRE technology) |
| | SRE sales/marketing efficiency (e.g., number of potential SRE customers contacted and targeted for SRE sales promotion) |
| | SRE development cycle time |
| | SRE source extraction rate |
| Reduce Carbon Footprint | $CO_2$ reduction rate |
| | $SO_2$ reduction rate |
| | Greenhouse gas (GHG) reduction volume |

**Table 3.** Customer Perspective.

| Goals | Performance Metrics |
| --- | --- |
| Sustain the Customer Relationship | Number of customer contact points |
| | Number of customer complaints in a given period |
| | SRE customer acquisition costs |
| | SRE customer conversion rate = (interactions with SRE customers who bought SRE)/(total SRE sales interactions with potential SRE customers) |

**Table 3.** *Cont.*

| Goals | Performance Metrics |
|---|---|
| | SRE customer retention rate = (number of customers who remain from the beginning to the end of a given period)/(total number of existing customers) |
| | SRE customer churn rate = (number of SRE customers lost in a given period)/(number of SRE customers at the SRE business start) |
| | SRE customer defection rate = (number of existing SRE customers defected to other alternative energy providers in a given period)/(number of SRE customers at the SRE business's start) |
| Improve Customer Satisfaction | SRE order fulfillment rate |
| | SRE customer value ratio |
| | Time to SRE market |
| | Frequency of interrupted SRE services |
| | SRE customer response time |
| | SRE customer service audit |
| Improve SRE Public Awareness | Public awareness rate |
| | Social or green marketing budget |
| | Number of the SRE business's social media followers |

**Table 4.** Innovation and learning perspective.

| Objective | KPI/Measure |
|---|---|
| Innovate SRE production and diffusion process | Industry/academia SRE research partnership |
| | Number of S&OP and quality circle brainstorming sessions |
| | SRE supply chain resilience = a reduction in chokepoints or bottlenecks |
| | Employee education and training budgets and frequencies |
| Enhance SRE supply chain visibility | Number of shared data sets among SRE supply chain partners |
| | Frequency of SRE joint demand planning |
| Improve R&D | Number of new, innovative SRE technology applications for patents |
| | Number of new patents granted to the SRE business |
| | Number of R&D project partners |
| | Amount of R&D grants awarded to the SRE business |

## 4. Summaries of Results and Conclusions

The success of SRE commercialization often hinges on various influential factors, such as target SRE market size, easy access to SRE sources, technological maturity, government/public support, and SRE supply chain efficiencies. Since each step of SRE production and diffusion poses complex challenges, viable strategic plans and performance monitoring systems must be developed. With this in mind, this paper proposed multiple visual-aid tools, such as strategy and supply chain maps and balanced scorecards, to systematically monitor and evaluate the SRE commercialization initiatives. Additionally, this paper makes theoretical and practical contributions to the body of RE literature. Theoretically, this paper is one of the few studies to develop easy-to-use visual-aid tools and specific performance metrics for improving the commercialization potential of SRE. In contrast with the traditional performance evaluation, the proposed metrics based on BSC shed light on four different perspectives of SRE creation and diffusion. To elaborate, graphical displays (via the strategy map) of the SRE commercialization plans allow the SRE business planners with limited technical knowledge and skills to fully understand the managerial ramifications of SRE production and diffusion, thus helping them make a wise strategic decision regarding SRE commercialization. In addition, this paper is one of the first to create supply chain maps to help SRE businesses visualize the potential weakest links of SRE supply chains and better prepare for SRE supply chain disruptions and subsequent SRE diffusion interruptions. Practically, this paper proposes specific strategic action plans and their priorities for commercializing SRE sources from multiple stakeholders' perspectives and thus reflects their varying viewpoints and interests. The reflection of these diverse viewpoints will obviate strong resistance from any stakeholder to the implementation of SRE commercialization strategies. Despite the numerous merits of this paper, this paper is far from perfect in that its proposed strategy and KPIs were not fully applied to the real-world setting.

However, as the SRE technology continues to evolve and advance, many variables that are believed to affect SRE production and diffusion efficiency may change. At the same time, their impacts may either diminish or increase. For example, the SRE production processes, such as energy/fuel extraction from wind, solar, and biomass and associated SRE diffusion processes, must be improved over time with advances in SRE technology. Thus, strategy and supply chain maps, along with performance metrics for SRE commercialization, should be constantly modified and updated. That is to say, future research should extend the current research framework by reflecting on such a change.

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