Resilience Is Paramount for Managing Socio-Technological Systems During and Post-Covid-19

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Abstract—*The spread of the coronavirus concomitant with the Covid-19 disease highlights the interconnectedness between systems that serve humanity. These systems are typically portrayed in economic, ecology and environment, physical/technological, and socio-political contexts and maybe delineated in terms of the interconnectedness between these contexts. Any delineated socio-technological system represents an intriguing class of interconnected systems in the novel era of* Society 5.0 *concomitant with fourth industrial revolution. This article describes a framework and resiliency model for socio-technological systems plus an application of the lens of vulnerability and resilience to a case study energy systems enterprise. It is intriguing that the energy systems enterprise is usurping extant socio-economic robustness thereby undergoing an absorptive phase of resilience. The discourse complements existing body of literature on energy systems and society by emphasizing that the principles of vulnerability and resilience are paramount for sustainable management of socio-technological systems, and more so in a post-Covid-19 world.*

Key words: Energy systems management, socio-technological systems, vulnerability and resilience

I. INTRODUCTION

THE incidence and on-going spread of coronavirus concomitant with Covid-19 disease are imposing unanticipated stressors on systems that serve humanity, and the pandemic, that is, both phenomena are manifesting unprecedented changes to society in general. Understanding how society is changing due to the pandemic provides impetus for articulating and implementing plausible responses to the stressors [1]. As tabulated in Figure 1, it can be argued that sustainability has become the dominant paradigm as transitions in the human civilization gain momentum in the novel era of *Society 5.0* [2], [3]. As this era evolves, it is widely anticipated that fourth industrial revolution (4IR) technologies will facilitate sustainable development, albeit that the "fusing" of the physical, digital, and biological worlds will impact "all disciplines, economies, and industries, and even challenge ideas about what it means to be human" [4].

It is remarkable that the authors in [5] used the trendy management acronym "VUCA" (*volatile, uncertain, complex,* and *ambiguous*) to characterize the era of *Society 5.0*. VUCA implies that the novel era features (i) unanticipated and unstable changes; (ii) cause and effect uncertainty; (iii) vagarious hyperinterconnectivity intercommunicability, and interdependency; and (iv) "unknown unknowns." Given the current situation of the pandemic, it is intriguing that the World Economic Forum's Global Risks Report 2020 [6] did not indicate the "spread of a virus" or "infectious diseases" in the top ten risks in terms of likelihood; however, "infectious diseases" is listed 10th in terms of impact. The salient point here is that the incidence and on-going spread of coronavirus concomitant with COVID-19 disease are more in tune with the VUCA characterization rather than the conventional concept of risk. The phrase "spread of coronavirus concomitant with COVID-19 disease" is preferred in this article because, from the viewpoint of resilience, the nature of stresses induced by the spread of the virus can be quite different from the stresses imposed by the disease, albeit that the respective stresses may be interrelated.

Interestingly, the media world of news is awash with countless commentaries on how to respond to the pandemic. Obviously, the immediate and initial focus has been on public health, followed by the economy. Most pundits (e.g., [7]–[11]) all suggest that dramatic changes in economic, fiscal, and monetary policies are necessary to respond to the pandemic. It is noteworthy that the WEF is rolling out a digital platform for the global business community to help address the impact of the pandemic [12]. The reality is that the pandemic has collateral ramifications across all domains and sectors of human endeavor and livelihood.

Curiously, there has not been a similar amount of attention on infrastructure, especially because the ramifications of the pandemic on infrastructure systems that underpin governance, commerce, and industry remain unprecedented. Invariably, any "infrastructure system that shuts down in an emergency or does not adapt to new realities can inhibit disaster response, cripple social cohesion, and stifle economic growth." Gadhi [13] posits that the pandemic provides an opportunity to integrate and streamline digital infrastructure for epidemic forecasting and decision-making at various stages of the public health response. An acknowledgment that "economic" infrastructure interdependencies [14] contain inherent vulnerabilities makes it paramount to build resiliency across the entire system that is encapsulated within ecology and the environment and consisting of socio-economic and cyberphysical components. An assertion by Howell [15] is that governments and businesses can confront the challenges imposed by the pandemic by learning about resilience.

In consonance with this VUCA reality, resilience, and vulnerability have taken on renewed significance for sustainable management of hyperinterconnected socio-economic and cyberphysical systems (CPS) that are encapsulated within ecology and the environment. A socio-technological energy system (STES) is a particular delineation within the context of hyperinterconnected socio-economic and CPS. Hence, the discourse in this article deals in part with the broader question of how to sustainably manage the delineated socio-technological system so as to cope with the ever-increasing demand for affordable and reliable energy.

The remainder of this article is structured as follows. A framework for socio-technological systems is conceptualized in Section II. A graphical model for the interpretation of vulnerability and resilience of socio-technological systems is presented in Section III. The framework and model is used to examine a case study STES in Section IV. The discourse interpolates some practical insights for infrastructure systems managers, policy makers, organizations, and society in general. Concluding remarks are provided in Section V.

II. Socio-Technological System

For the purposes of this discourse, a socio-technological system arises from digitalized technology fusion of socio-economic systems (SES) with CPS as encapsulated within the world of ecology and the environment (see Figure 2).

This means that the infrastructure for education, energy and water, health, security, and transportation, etc., are inextricably interwoven with socio-economic business activities in the service of humanity. After all, technological revolutions in infrastructure influence economic [16], [17] and societal transformations [18], and vice versa.

Energy infrastructure is an example of a CPS. It consists of equipment,

Era				
Industrial Revolution	*Characteristic*	*Paradigm*	*Society*	*Characteristic*
-		*Ancient or Pre-Modern*	1.0	▪ Gathering & hunting ▪ Survival of early societies
1.0	• Steam power • Mechanization • Knowledge formulation	*Modern*	2.0	▪ Agricultural ▪ Rapid formalisation of societies ▪ Fragmented industrialisation
2.0	• Electricity • Mass production • Knowledge evolution		3.0	▪ Massive industrialisation ▪ Effectiveness ▪ Geopolitics
3.0	• Information technology • Automation • Knowledge distribution		4.0	▪ Globalized industries, institutions & markets ▪ Global connectivity ▪ Global dependency
4.0	• VUCA • Cyber physical systems • Knowledge mutation	*Sustainability*	5.0	▪ VUCA (volatile, uncertain, complex, ambiguous) ▪ Information about everything ▪ Instant gratification

Figure 1. Tabulation of eras of human civilization.

machinery, and facilities engineered in such a manner that the operations of the elements and subsystems are monitored, coordinated, controlled, and integrated via computing and information communications technologies. Similarly, an SES is constituted by various interacting agents (i.e., actors and role players) such as individuals, public and private institutions, interest groups, firms, industries, markets, etc. The configuration of interactions and relationships between the SES constituents, and hence, their respective behaviors, functions, and performances are generally regulated by norms, rules, and statutes (cf., [19]).

As may be deduced from Figure 2, a socio-technological system encompasses interdependent, interrelated, communicative, and intelligent constituents, elements and subsystems that combine into a logically coherent whole. In the era of Society 5.0, it is assumed that the interactions, interdependencies, and interrelationships are facilitated through digitalized 4IR technology platforms. A prevailing presumption is that the behavior, functioning, and performance of the overall system should be better or greater than the sum of the individual behaviors, functions, and performances of the respective components [20].

The 4IR parlance of Internet-of-Things (IoT) presupposes that every component (i.e., constituent, element, and/or subsystem) of a socio-technological system can interconnect and intercommunicate. Such hyperconnectivity and communicability surmises "information of everything" [21] and "information about anything" as pervading clichés of the novel era. This means that every IoT-enabled component can be treated as a node, and the linking of the nodes establishes networks within the socio-technological system. With the proviso that each node can be linked to another, then, the linking of all the nodes establishes a meshed network topology which comprises $l = \frac{n(n-1)}{2}$ links; where n is the number of nodes and l is the number of links. Each link will have a weight $w_{i,\, i=1\ldots l}$ that determines the relative strength of the interactions, interrelationships, and interdependencies between the respective nodes in the network. Theoretically, there are many possible topologies of networks in a socio-technological system; and it is conceivable that the linkages and networks within the socio-technological system will evolve and transform in response to stressors that emanate from changing circumstances; albeit that the stressors may be endogenous and/or exogenous to the system.

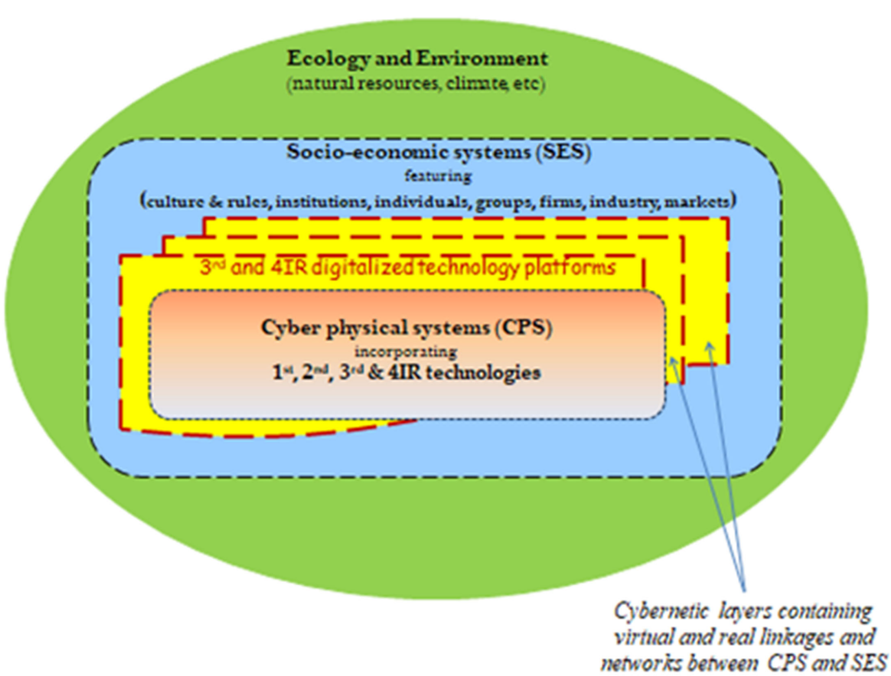


Figure 2. Socio-technological system concept.

III. Resilience and Vulnerability

A. Vulnerability Intriguingly, vulnerability is often brushed over in extant literature on resilience. However, the on-going complex and unwelcome consequences of the pandemic highlight the exposure or susceptibility of globalized and localized socio-technological systems to the incidence and spread of the virus and disease. A system is regarded as being vulnerable [22], [23] if the intrinsic or inherent weaknesses are without protection. This subsumes that an interconnected system contains intrinsic or inherent weaknesses; and such vulnerabilities could be associated either with one or several components, linkages, or networks existing within the socio-technological system. An "attack" on any exposed or susceptible component, link, or network could cause the attacked item, as well as the socio-technological system to exhibit extraordinary behavior, functionality, and performance.

Noting that CPS are embedded within and fused into the socio-economic "world" via digitalized technology platforms, then vulnerability can be defined as the degree to which the components, links, and networks of a socio-technological system are exposed to, or susceptible to stressors. A system where the vulnerabilities are not protected will likely exhibit extraordinary behavior, functionality, and performance when subjected to stressors arising from changing circumstances. Thus, it is the responsibility of the management to identify weaknesses inherent in or associated with a system, and to ensure that such vulnerabilities are either eliminated or protected against change inducing stressors that may particularly undermine the behavior, functioning, and performance of the system. As a corollary, it seems more plausible to confront vulnerability by building resilience so that the extraordinary behavior, functioning, and performance becomes more manageable when a socio-technological system is challenged by stressors attributable to transient, intransigent, or evolutionary change circumstances.

B. Resilience A generic definition of resilience is "the capacity to recover quickly from difficulties." The term has also been defined from many perspectives, especially from environmental, engineering/technical, and sociology perspectives (see, for example, [24]–[28]). The authors in [29] and [30] provide useful discourse on the multiplicity of definitions and challenges that may be associated with applying the concept of resilience in policy and practice. The multiplicity of definitions vis-à-vis arguments and reservations associated with the application of resilience are acknowledged. However, the discourse here concurs with the "pragmatic" multidisciplinary perspective expressed in [31] to broadly define the resilience for a socio-technological system as *systemic capabilities to accommodate* the effects of *change stressors*. This definition leads to six lemmas highlighted as follows.

First, *systemic* refers to the entire socio-technological system. Second, *capabilities* imply that the system contains dynamic processes, and also that the system possesses ability with capacity to change with time. Third, *accommodate* means that the system can and should capably "absorb," "recover," and "restore," as well as "adapt" and "evolve" whilst confronting changing circumstances. Fourth, a *change* circumstance may contain combinations of transient, intransigent, and evolutionary stressors. Transient stressors can temporarily interrupt the normative behavior, functioning, and performance of the system. Intransigent stressors can cause permanent deviation in the behavior, functioning, and performance of a socio-technological system. Evolutionary stressors can induce transformation and necessitate evolution in the behavior, functioning, and performance of the system. From the widest viewpoint of uncertainty, *change* circumstances may be perceived as positive or negative. In fact, it can be argued that the prevalence of negativism in discourse on resilience more or less originates from the limiting concept of risk.

The fifth lemma is that a *change* circumstance can originate from events and sources endogenous to the socio-technological system (e.g., asymptomatic and community transmission of coronavirus, change in the fiscal policy, microeconomic perturbation, political instability, protests and riots, malfunction or technical failure of infrastructure). Otherwise, the origin of stressors could be from events and sources perceived to be external to the socio-technological system (e.g., global spread of coronavirus, global financial crises, climate change, earthquakes, tsunamis), or *vis major* events that remain exogenous to the system (e.g., meteorite landings). The source and nature of the stressors may either be known or uncertain.

The sixth lemma is that transient, intransigent, or evolutionary stressors can activate dormant nodes, links and/or create new links and networks between the components of a socio-technological system. Such activation of dormant nodes, and/or creation of new links and networks may not only cause or induce extraordinariness in the behavior, functioning and performance of the respective components but also, can cause or induce unpredictability in the overall behavior, functioning, and performance of the socio-technological system. The six lemmas form the basis of the graphical model as articulated in Figure 3.

The wavy band indicates that the socio-technological system can exhibit a broad range of normative behavior, functionality and performance such that an initial response to a change stress can be atypical. The graphical model leads to a postulation that a socio-technological system can exhibit three stages (or five phases) of resiliency, as follows.

1) *Absorptive* resilience stage—with capacity to (i) absorb the effects caused by transient stressors (phase 1), (ii) recover from effects of the transient stressors (phase 2), and (iii) restore vital nodes, links, and networks toward normative behavior, functioning, and performance following the aftermath of the transient stressors (phase 3).
2) *Adaptive* resilience stage—which encompasses the absorptive stage and includes capacity to (iv) adapt with respect to intransigent stressors (phase 4). That is, the nodes, links and networks must restructure in a stable manner to sustain acceptable overall behavior, functioning, and performance.
3) *Transformative/Evolutionary* resilience stage—encompassing absorptive and adaptive stages but including the capacity to (v) transform and evolve with respect to evolutionary stressors

(phase 5). That is, the nodes, links, and networks must continuously restructure in an evolutionary but sustainable manner so that the system can attain desirable behavior, functioning, and performance within acceptable time frames.

From a management viewpoint, resilience may also be interpreted in terms of two constructs, viz:– *robustness* and *resourcefulness* (see Figure 3). First, *robustness* describes the extent of extraordinary change (in behavior, functionality, and performance) that the socio-technological system can exhibit. Invariably, robustness incorporates redundancy in that it encompasses the system's capacity to absorb change—that is, the availability of excess capacity. The excess capacity may be created *a priori* through (i) hardware redundancy in the cyberphysical components, as well as (ii)`` at the organizational, and (iii) human level of the socio-economic constituents that comprise the overall system. The first measure of robustness relates to the extent of abnormal functioning, the second relates to the extent of change in performance, and the third relates to the extent of extraordinariness in the behavior of a socio-technological system. Paraphrasing Howell [15], robustness means proactively designing redundancies, fail-safes, and firewalls into nodes, linkages, and networks that comprise the socio-technological system. In this way, robustness can engender modularized chains of command for effective decision-making whilst the system is encountering stressors imposed by changing circumstances.

Second, *resourcefulness* describes the system's ability to recover and, where necessary, restore to its normative behavior, functioning, and performance. In any case, *resourcefulness* encompasses all the five phases of resiliency depicted in Figure 3. Resourcefulness incorporates responsiveness and further describes the system's agility and flexibility. In essence, resourcefulness surmises the ability to mobilize redundant components and constituents, as well as activation of dormant nodes, linkages, and networks to ensure that the system can absorb, recover, restore, adapt, transform, and evolve in accordance to transient, intransigent, and evolutionary stressors. An approach to establishing resourcefulness is to identify and align the synergies inherent in a socio-technological system. This means continuous identification of redundant components and constituents, synergistic nodes, linkages, and networks that can engender combined behavior, functioning, and performance that will sustain under changing circumstances. In essence, this explains what is being recommended by some of the pundits cited earlier in Section I of this article.

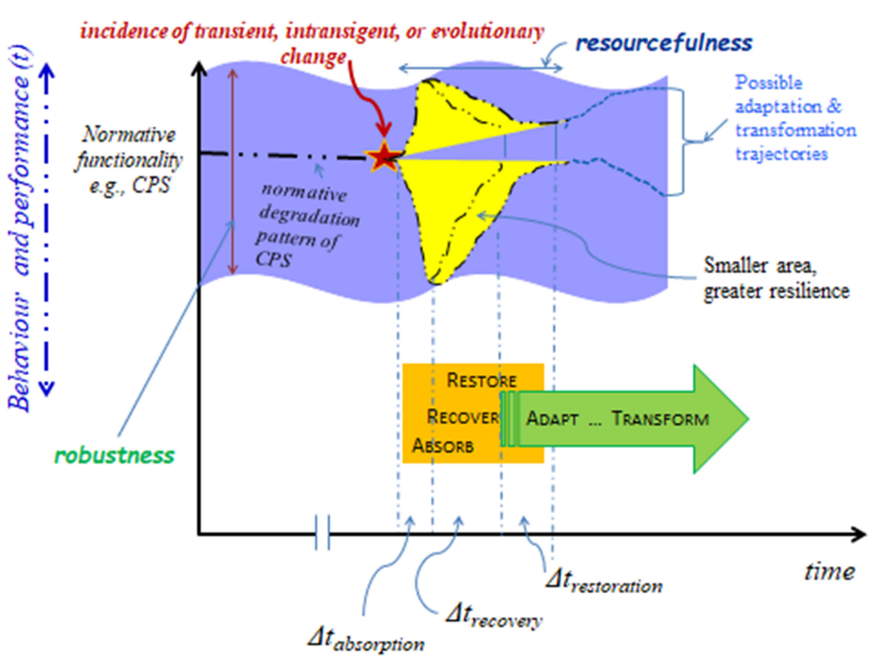


Figure 3. Graphical articulation of resilience for a socio-technological system.

For brevity, the product of (*robustness x resourcefulness*) provides a measure of resiliency (see Figure 3). The phases/stages of resiliency depicted in the graphical model are consistent with the paradigm of sustainability—defined here as *the attainment of dynamic equilibrium in realizing the optimum value within a socio-technological system with concurrent minimization of adverse impacts on business, society, ecology, and the environment.* Therefore, the model can be applied to geographical, regional, sectoral, or country-wide portrayals of socio-technological systems. In this regard, a brief review of some notable literature on the resilience of socio-technical systems is provided as follows.

C. Managing Resilience of Socio-Technical Systems

The framework (see Figure 2) and graphical model (see Figure 3) serve to eliminate inconsistency in the study of resilience of socio-technological systems. In the first instance, extraordinariness can either be positivistic or negativistic, or both. That is, the depiction of robustness cannot be limited to a negative perception of uncertainty in terms of behavior that manifests in functional deterioration or degradation in performance of a socio-technological system. Extrapolating from [25], the behavior (i.e., the interactions and interrelationships between the cultural and structural elements) of a social system “conforms to a multiphase, multiscaled heuristic model, the base unit of which is a temporally dynamic process . . .” In other words, the assertion in [25] simply reiterates that there are three types of resilience, viz:– (i) resilience to transient change stressors (re: Type I), (ii) resilience to intransigent change stressors (re: Type II), and (iii) resilience to evolutionary or transformative change stressors (re: Type III).

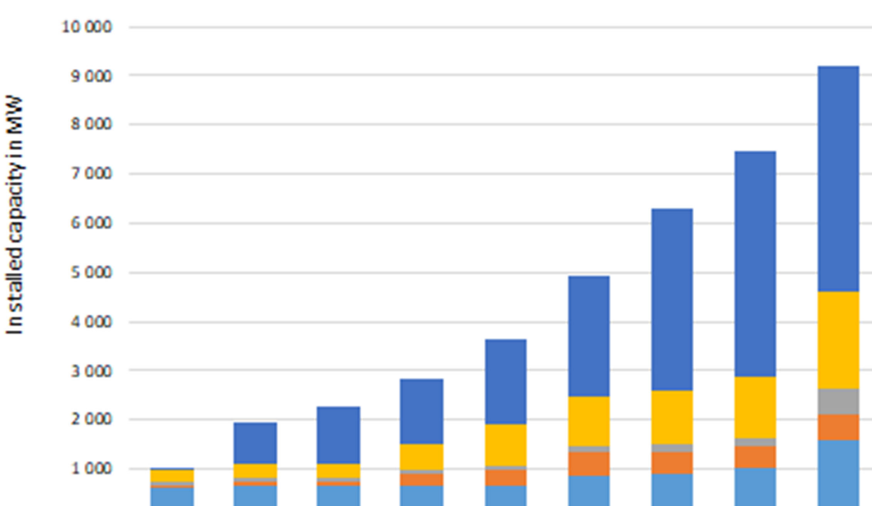
Ruault *et al.* [32] discuss socio-technical systems resilience from the conventional risk viewpoint of systems engineering. They posit that a socio-technical system can be articulated in three levels—(i) the human level, (ii) the technical system level, and (iii) the organizational level. Following their case study of a railway accident, they argue that the resilience of the associated socio-technical system can be examined in terms of the dissonance between the levels.

Ruth and Goessling-Reisemann [28] and Doorn [33] summarize how interactions between respective social and cyberphysical subsystems promote or undermine the resilience of either type of system, thus, impacting upon the resilience of the overall socio-technological system. The implicit and normative perception is that the resilience of the overall socio-technological system should prevail, even if some components and constituents may have to be sacrificed in tandem.

From a management viewpoint, the challenge remains as to which component/constituent(s) should be sacrificed in order to assure a desirable level of overall system resilience. Thus, management is confronted by the following imperatives.

1) Assure that the socio-technological system will recover and be restored to its normative state.
2) Guarantee that the socio-technological system can adapt to a new but sustainable state.
3) Accept that the socio-technological system will evolve and hence prepare for the transformation to sustainable state.
4) Articulate and develop options for mitigation, adaptation, and transformation in recognition that the socio-technological system may transition to a state determined by part combinations of states A, B, and C.

In the following section, the framework and model are applied to examine a case study socio-technological system portrayed from the viewpoint of an energy enterprise.



	2010	2011	2012	2013	2014	2015	2016	2017	2018
South Africa	12	811	1 150	1 331	1 732	2 431	3 669	4 602	4602
Morocco	255	289	291	531	838	999	1 101	1 225	1958
Kenya	73	74	76	80	90	145	146	152	517
Ethiopia	21	103	103	256	322	475	480	478	528
Egypt	632	652	652	652	652	862	885	1 006	1587

Figure 4. Cumulative renewable energy installations in selected developing countries (Source [34 - IRENA (2019)]).

IV. Case Study: STES

As stated earlier in Section I of this article, infrastructure that does not adapt to new realities can inhibit disaster response, and “the cost to [manage] infrastructure not built to accommodate a changing world can be prohibitive.” The statement is particularly applicable now and also in a post-Covid-19 world, given the assertion that 4IR technologies have the potential to transform entire infrastructure systems so as to address the energy needs of Society 5.0 livelihood and living experience. The discourse in this article deals in part with the broader question of how to sustainably manage a delineation of a socio-technological system so as to meet the ever-increasing demand for affordable and reliable energy. The discussion that follows will more or less emphasize the dissonance between the organization level and the technical system of the energy delineated socio-technological system, notwithstanding that the human level is no less as important.

As depicted in Figure 4, emerging economies are expected to experience the highest growth in energy demand, and it is acknowledged that renewable source technologies will increasingly be introduced and deployed toward meeting the anticipated growth in energy demand.

Restating the obvious, the challenge of integrating renewable and legacy technologies is typically exacerbated by the complex conflation of issues of governance, markets, regulation, social and economic inclusivity, etc. Thus, in many developing and even developed economies, there are often zealous debates around the structure, legislation, regulation, and management of STESs. In the case study country, there are on-going vociferous arguments for and against restructuring of the vertically integrated, energy monopoly enterprise.

An interpretation of the case study STES is illustrated in Figure 5, highlighting energy infrastructure as the cyberphysical system with governance institutions, special interest groups, energy business enterprise, and customers as the socio-economic constituents. The core of the STES is a tightly connected generation, transmission, and distribution/reticulation infrastructure, which is completely controlled by a vertically integrated business enterprise.

The electricity monopoly is primarily fossil-based, and increasing concerns about the environment have provided impetus to pursue the integration of renewable and legacy technologies. Revenue for the enterprise is derived from a variety of customers, especially the historically key industrial consumers of electricity. The customers who desire a normative behavior, functioning, and performance of the STES interface directly with the energy infrastructure. Here, normative behavior, functioning, and performance include, *inter alia*, affordable and stable tariffs, reliable supply and quality service. It is worth mentioning that a significant portion of the tariffs is bound in long-term agreements with the key industrial consumers. The legacy long-term contracts were established to guarantee security of supply whilst mitigating economic sabotage during a defunct apartheid regime that featured absolute and dehumanizing political and socio-economic exclusivity.

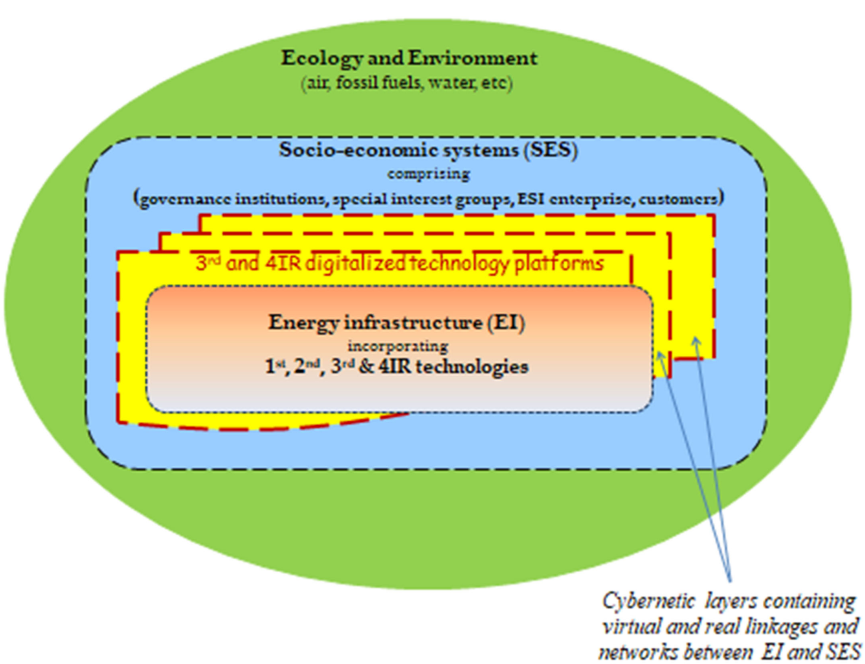


Figure 5. Case study STES.

The vertically integrated energy enterprise is wholly owned and controlled by a government that is represented by a number of public institutions. Invariably, the multifarious representation of the sole shareholder has created perplexing accountabilities and responsibilities within the STES. For instance, the government policy revolves around a strong ideological stance of utilizing the energy enterprise to deliver on short-term as well as long-term socio-economic objectives. This strong ideological stance tends to be diminished due to political wrangling between the representative governance institutions. Ambiguity and vagueness in governance and regulation inadvertently accentuate the monopolistic control of the energy enterprise as the respective public institutions, key industrial consumers, and special interest groups vociferously argue to remain tightly connected to the energy enterprise well beyond the cybernetic layer.

The STES also features a variety of interest groups among its stakeholders. Some of the interest groups interface with the energy enterprise only at the cybernetic layer. Others (e.g., trade unions) and also the public institutions interface with the business enterprise beyond the cybernetic layer. Inextricably, several of the social constituents of the STES interface directly with the energy infrastructure. For example, special customers such as municipalities and key industrial consumers directly interface with the cyberphysical components of the energy infrastructure.

Figure 5 intrinsically implies that there are linkages between the socio-economic constituents and cyberphysical elements (i.e., nonbehavioral components) of the STES. In essence, the socio-economic constituents or behavioral components, that is, the governance institutions, interest groups, customers, and energy infrastructure business organization are multifaceted and digitally interconnected and, they are also interconnected to the cyberphysical components of the STES through various digitalized technology platforms. Some of the links and networks between the STES components have been established in cyberspace through more formal means, i.e., legislation, regulations, and standards, other links and networks have been established via cultural or traditional conventions.

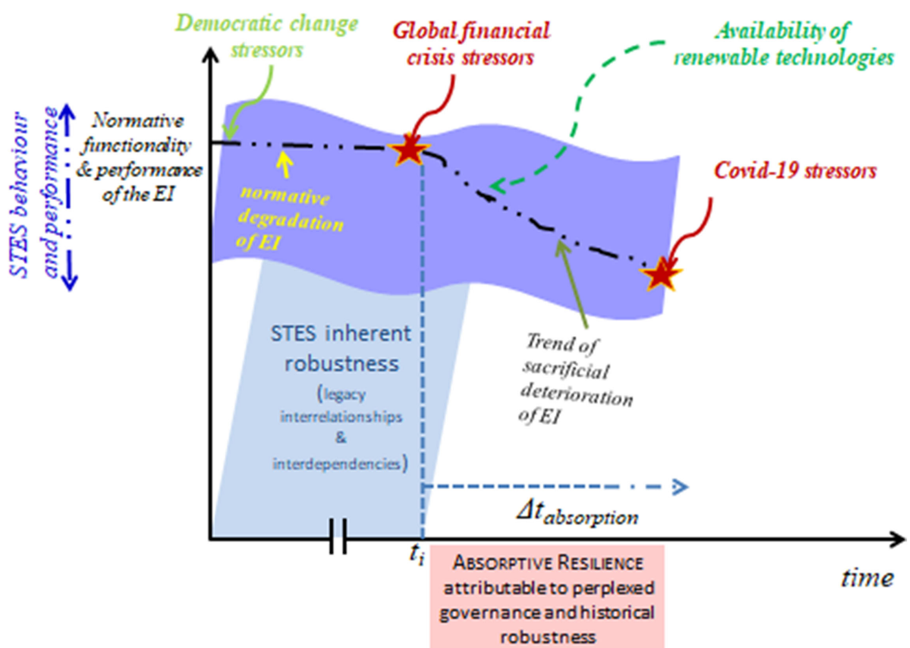
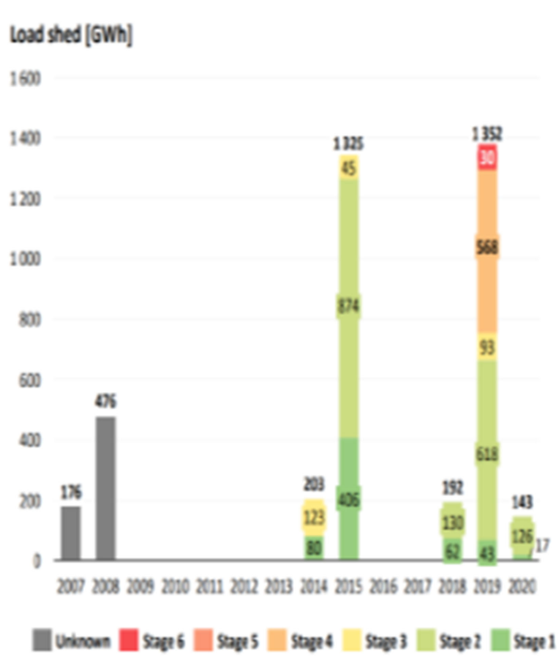


Figure 6. Absorptive resilience phase of case study STES.



Year	Duration of outages (hours)	Energy shed (GWh)	Est. econ. Impact (ZAR-bn)
2007	-	176	8-15
2008	-	476	21-42
...	...	...	...
2014	121	203	9-18
2015	852	1325	58-116
2016	-	-	-
2017	-	-	-
2018	127	192	8-17
2019	530	1352	59-118
2020 (YTD)	80	143	6-12

Figure 7. Portrayal of increasing instances of load shedding over longer periods of time for Case Study STES (Source [36]).

For example, ownership and control of the energy assets have been established by law while relationships between trade unions and the physical assets are more or less conventionally defined. The networks of interactions, interrelationships, and interdependencies between the respective socio-economic and cyberphysical components, as well as the intercommunicability among and between all the STES components are all facilitated by virtual and real linkages.

From the viewpoint of resilience, there are various networks between the components of the STES and the linkages determine both the robustness and vulnerabilities associated with the overall system. The goal for each behavioral component of the STES is to achieve its own objectives, and in the course of doing so, each constituent introduces change into the STES. At certain periods in time, the behavioral components may align toward particular objectives, and such alignment introduces endogenous change that not only creates new networks and linkages but also sustains existing networks by strengthening the necessary linkages.

As reported in [35] and mentioned earlier, specialized linkages and networks were historically established between the sole shareholder, the energy utility, and the key industrial consumers during a previously exclusive political and socio-economic dispensation. It is arguable that over time, the legacy linkages and networks implanted a certain level of robustness within the STES, corresponding to the impartation of absorptive resilience toward certain kinds of change stressors. The strong ideological stance of the current democratic dispensation to deliver on short term as well as long term socio-economic objectives seemingly encourages a culture of expropriating the existing structure of the energy enterprise. Furthermore, there are ongoing perplexities in accountabilities, decisions, and responsibilities of the governance institutions. The perplexities coupled with political patronage of special interest groups inadvertently influence agility and flexibility in decision-making and forecasting, as well responsiveness to change stressors. The inextricable effect is accentuation of robustness within the socio-economic components of the STES, thereby also accentuating absorptive resilience of the energy systems enterprise, i.e., stretching $\Delta t_{\text{absorption}}$, as depicted in Figure 6 (refer also to Figure 3).

The shapes and lines depicted in Figure 6 are derived from agglomerating publicly available data and information. For example, the supporting evidence in Figure 7 shows Wright and Calitz's [36] portrayal of increasing instances of load shedding over longer periods of time. Paradoxically, fewer instances of load shedding are being observed during Covid-19 restrictions and corresponding slowdown in economic activities!

The agglomerated data and information point toward increasingly abnormal behavior, functioning, and performance of the case study STES. It can be argued that the historical implantation of robustness in the socio-economic constituents seemingly engenders absorptive resilience which, in turn, inadvertently manifests in the observed sacrificial deterioration of the cyberphysical energy infrastructure. Curiously, the deterioration is taking place despite the introduction of renewable energy technologies in the case study STES. The prevailing negativism may be construed as an indication of poor resourcefulness (i.e., poor agility, apparent inflexibility, weak responsiveness toward mobilizing and integrating renewable technologies) within the case study STES.

V. Conclusion

The case study supports the conceptualization of a socio-technological system in terms of digitalized technology fusion of SES with CPS as encapsulated within the world of ecology and the environment. The fusion means that a socio-technological system contains inherent vulnerabilities consequent upon the interactions, interrelationships (i.e., linkages), and interdependencies (i.e., networks) that are intrinsically established between the behavioral and nonbehavioral components both in the virtual (cyber) and the physical realms. In the first instance, the existence of inherent vulnerabilities means that it is imperative to build resiliency across the entire socio-technological system.

In the second instance, the incidence and spread of coronavirus concomitant with Covid-19 disease manifest as VUCA challenges. Under Covid-19, there is evidence that digitalized technologies are propping up human livelihood in the current situation of diminished commerce and industry. Therefore, emerging 4IR technologies must be appropriately exploited toward *Society 5.0* vision of sustainable human-centeredness in governance [37], industry [38], and commerce [39]. It is worth reiterating the statement by Parmar and Bhardwaj [40] that "we can build a better world after Covid-19 by dragging the state back into public services."

As cited in Section I of this article, most pundits emphasize that it is paramount to build long-term resilience across the entire socio-technological system. Building long-term resilience requires continuous integration of robustness and resourcefulness in a manner that demands compliance with the paradigm of sustainability. Hence, the proposition in this article remains that the principles of vulnerability and resilience are paramount for sustainable management of socio-technological systems, and more so in a post-Covid-19 world.

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