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## A hover view over effectual approaches on pandemic management for sustainable cities – The endowment of prospective technologies with revitalization strategies

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### ABSTRACT

The COVID-19 pandemic affects all of society and hinders day-to-day activities from a straightforward perspective. The pandemic has an influential impact on almost everything and the characteristics of the pandemic remain unclear. This ultimately leads to ineffective strategic planning to manage the pandemic. This study aims to elucidate the typical pandemic characteristics in line with various temporal phases and its associated measures that proved effective in controlling the pandemic. Besides, an insight into diverse country's approaches towards pandemic and their consequences is provided in brief. Understanding the role of technologies in supporting humanity gives new perspectives to effectively manage the pandemic. Such role of technologies is expressed from the viewpoint of seamless connectivity, rapid communication, mobility, technological influence in healthcare, digitalization influence, surveillance and security, Artificial Intelligence (AI), and Internet of Things (IoT). Furthermore, some insightful scenarios are framed where the full-fledged implementation of technologies is assumed, and the reflected pandemic impacts in such scenarios are analyzed. The framed scenarios revolve around the digitalized energy sector, an enhanced supply chain system with effective customer-retailer relationships to support the city during the pandemic scenario, and an advanced tracking system for containing virus spread. The study is further extended to frame revitalization strategies to highlight the expertise where significant attention needs to be provided in the post-pandemic period as well as to nurture sustainable development. Finally, the current pandemic scenario is analyzed in terms of occurred changes and is mapped into SWOT factors. Using Fuzzy Technique for Order of Preference by Similarity to Ideal Solution based Multi-Criteria Decision Analysis, these SWOT factors are analyzed to determine where prioritized efforts are needed to focus so as to traverse towards sustainable cities. The results indicate that the enhanced crisis management ability and situational need to restructure the economic model emerges to be the most-significant SWOT factor that can ultimately support humanity for making the cities sustainable.

### 1. Introduction

The coronavirus has found its pathway to infect humans and it emerged as a pandemic very quickly. Originating from China, the Coronavirus Disease (COVID-19) has managed to spread to most of the regions of the world and put millions of human lives under threat

(Razzaq, Sharif, Aziz, Irfan, & Jermisittiparsert, 2020). According to the WHO situational weekly report, dated 29 December 2020, the reported COVID-19 positive cases had surpassed 79.2M with 1.7M deaths worldwide (WHO, 2020a). The pandemic thus caused a reverberating effect on humanity in terms of health, economy, development, lifestyle, and the like. It is clear that humans were not prepared for this pandemic

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despite the progress previously made in related technology and development. If unable to respond well to the pandemic, it will be reflected in massive numbers of deaths than the lives lost in the World Wars. Human activities are significantly affecting the environment and the climate system of the planet. In turn, these climate changes pose severe weather events, natural disasters and public health threats (Irfan et al., 2019). Hence, it is of utmost importance that humanity should figure out an effectual method to tackle these events. In a city, when a pandemic prevails, the role of different social bodies such as the government,

healthcare, industries and the public is significant, and each of them influences the effectiveness of a response towards the pandemic (Kumaravel, Subramani, Sivakumar, Madurai Elavarasan, & Vetrivelvan, 2020). The interrelations among these social bodies need to be strengthened to fight against the unexpected enemy. This makes it essential for us to search for the answers concerning the various perspectives of pandemics. This includes framing a typical response to the pandemic from what humanity has experienced in the past. Further, by analyzing the influence of the interrelated social bodies on the pandemic

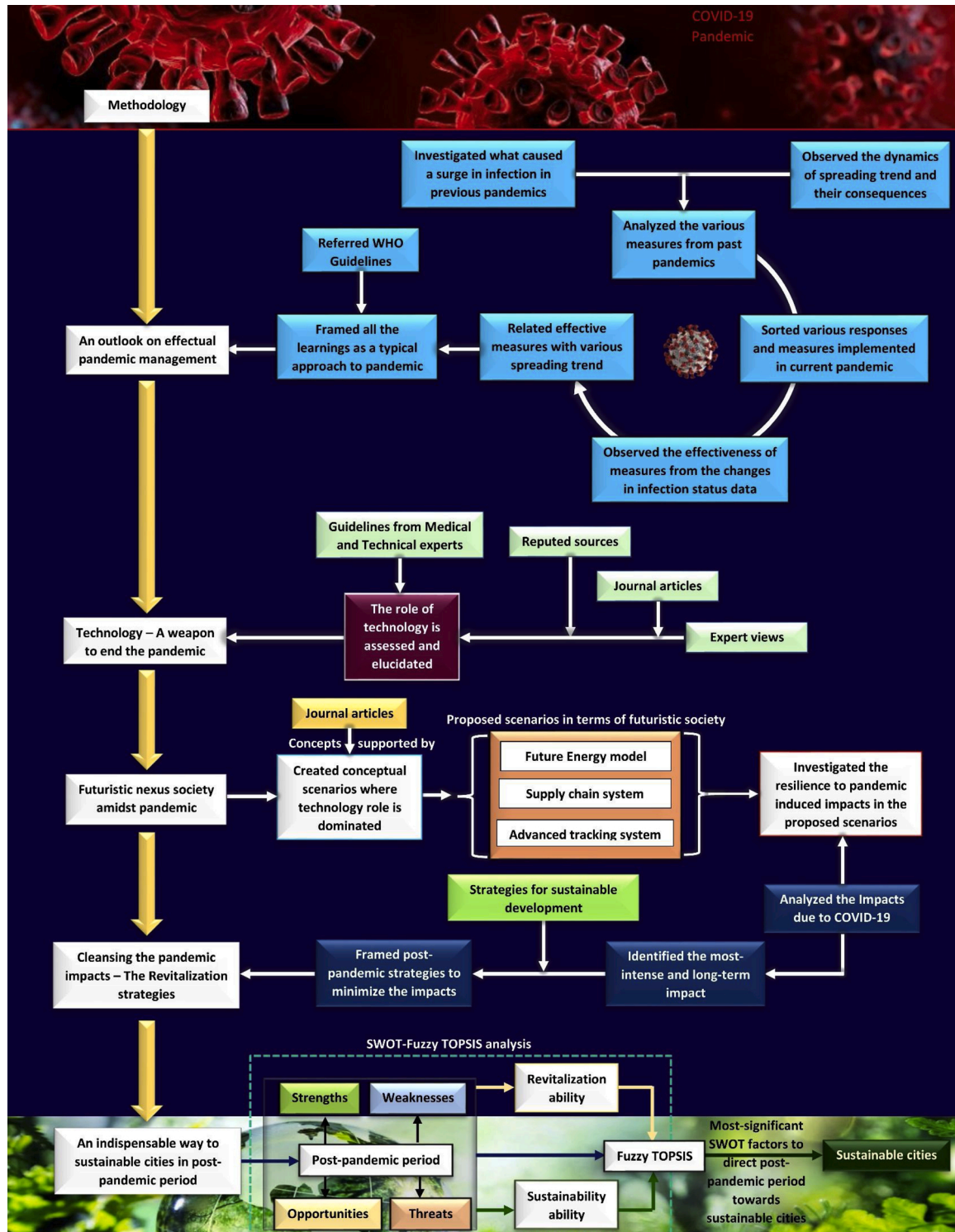


Fig. 1. Methodology of the study.

crisis, understanding the varying degrees of influence exerted by them, and knowing how big the roles each can play in suppressing the pandemic, the mistakes can be avoided. Moreover, learning from the ways that the different countries tried in dealing with the pandemic in terms of their special measures implemented and the take away lessons from each incident is pivotal. With appropriate interpretation and implementation of the knowledge and experience gained, humanity can not only thrive under pandemic scenarios but can also progress towards sustainability.

The consequential menaces of a pandemic can be either more intensive or attenuated depending on the actions that are taken in mitigating the spread. The widespread catastrophe that results in the aftermath of the pandemic is the economic depression which is one among such consequential menaces. Taking specific responses promptly at the appropriate timing corresponding to the different phases of a pandemic is required to minimize the extent of significant impacts. In such cases, there is a need to understand the characteristics of the pandemic's progress and, simultaneously, the details about what strategies can ultimately help in bringing the city back to normal functioning and when to impose such strategies matters. Thus, managing the transition from the pandemic to the post-pandemic phase needs a tactical approach that most people fail to understand. In addition, during the progress from the pre-pandemic to the end of the pandemic, some crucial factors help in mitigating the spread, and giving close attention to such factors is vital. These factors include technology, risk management, communication, and other influencing variables that drive the city. Hence, increasing or optimizing the utilization of these influential factors and understanding their role amidst the pandemic is significant. Also, developments in the near-future should take place in such a way that the system becomes more efficient, effective, flexible, and reliable, which, in the fullness of the time, can lead us to sustainability.

Regarding the pandemic management, studies have been reported with different approaches and analysis in controlling the pandemic. [Krumkamp et al. \(2009\)](#) evaluated pandemic national control policies through a hazard analysis of critical control points. Such analysis infers the essentiality of transparent communication, well-structured responsibilities, and harmonized policy guidelines in managing pandemics. At the same time, evidential research on various influencing factors such as cultural factors and environmental factors has been studied and analyzed ([Rahmani & Mirmahaleh, 2021](#)). Some studies have proposed the whole-of-society approach to deal with the pandemic. Such an approach demands trust development among every individual, distribution of resources, enhanced cooperation and consensus-oriented decision making among various levels of governments, business units and public members. [Schwartz and Yen \(2017\)](#) analyzed the whole-of-society approach to pandemic response with Taiwan as a case study and the authors recommended such an approach to other countries' governments too. Moreover, the implementation of the whole-of-society model would also bring harmony and focused responses with synergistic benefits to the whole humanity ([Dubb, 2020](#)). A 2020 study claims that humanity needs to call for a "One Health Approach" to tackle the pandemic which represents a collaborative effort to deal with complex problems at local, national, and global levels by engaging professionals from multiple disciplines involving clinicians, epidemiologists, politicians, economists, researchers, scientists, and even the public ([El Zowalaty & Järhult, 2020](#)). But the decisions of governments, responses to the pandemic, global collaborative circle have an extra role in controlling the pandemics and suppressing their effects. [Mas-Coma, Jones, and Marty \(2020\)](#) raise several crucial questions and extrapolate the lessons that need to be learned from COVID-19 and explicitly set out scenarios of the short-, mid-, and long-term outcomes of the crisis that can possibly occur. Another study identifies 12 lessons from the management of the COVID-19 pandemic that should be instituted in future outbreaks such as transparency, decisive leadership, unified responses, effective communication, global solidarity and many

others ([Forman, Atun, McKee, & Mossialos, 2020](#)). Thus, understanding the nuances in controlling this pandemic and incorporating the lessons learned from different scenarios in different geographical areas is indispensable in the next inevitable pandemic as the changing world and globalization enhance the probability of its occurrence ([Perlman, 2020](#)).

It can be observed from the relevant studies that most of them focus on a general approach towards pandemic management such as One Health, Whole-of-the-society and other similar analysis. But these might not be practically feasible as many other influential parameters like policies and varied political approaches at different geographical regions, different degrees of prioritization of various social bodies, unexpected situations and technology have dominant roles to play in pandemic management. Thus, undertaking in-depth analysis on the various practical measures implemented and their consequences, innovations in approaches, and maintaining a social balance is a desideratum. Though some studies provide such standards of analysis and depict the lessons learned from the current pandemic, the extrapolation of these analyses in terms of effectiveness is missing. Thus, the research question have been formulated as:

- What are the characteristics of the progress of pandemic and how to effectively deal with the typical pandemic crisis (from a management perspective)?
- What is the role of technologies in managing the pandemic and how it aids in minimizing the pandemic impacts in a technology-empowered society?
- What are the post-pandemic strategies to minimize the pandemic impacts and to make the cities sustainable?

The contribution of this study focuses on answering these research questions, which include characterizing the pandemic and how a pandemic should be approached at different phases, the roles of social bodies, and the influence of their interdependence on the pandemic. Also, a brief insight is provided on how technology can influence the response towards pandemic management, and an analysis on the changes in pandemic response in terms of a futuristic city is presented. On the other hand, the possible revitalization measures to minimize the impacts in the post-pandemic world and directions to sustainable cities are provided. Hence, the approach of the analysis conducted in this study claim novelty through the different means of pandemic control factors being rendered as a function of time and directing such factors towards a focus on future sustainability. The methodology by which each section is structured is presented in [Fig. 1](#). The outcomes of this study are as follows:

- Understanding a typical pandemic and the effective strategies that can be adopted to address the different phases.
- Analyzing the approaches of various countries towards the pandemic, recognizing their uniqueness, and elucidating the lessons learned from them.
- Revealing the role of technologies in tackling the pandemic.
- The response of technology-empowered prospective cities in terms of digitalized energy sector, enhanced supply chain management, and advanced tracing system towards the pandemic.
- Post-pandemic strategies to revitalize the cities from pandemic impacts.
- Identifying the most significant factors that direct towards sustainable cities using a hybrid SWOT-Fuzzy TOPSIS methodology.

## 2. An outlook on effectual pandemic management

The spread of the Corona Virus Disease-2019 (COVID-19) has resulted in a situation of pandemic which puts all of humanity in jeopardy. Many approaches have been framed by experts to deal with the pandemic and we will discuss in this section how a typical pandemic should be dealt with. This section also presents the responses of certain



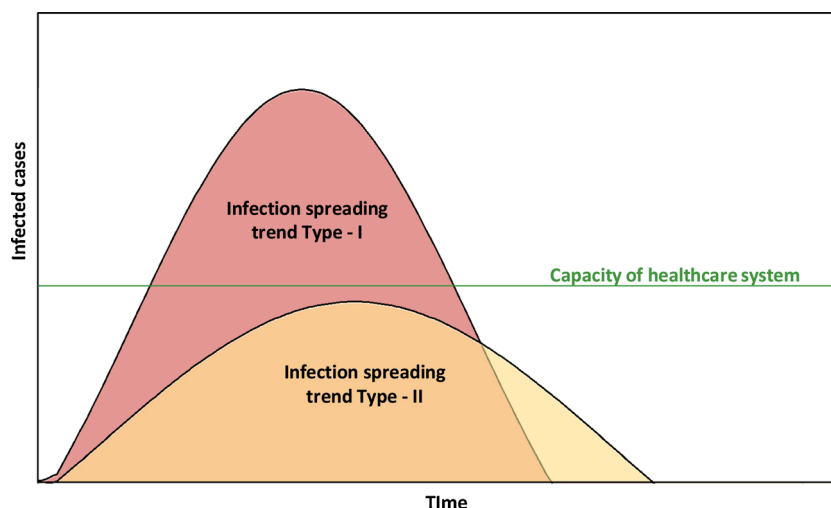


Fig. 2. Characteristics of pandemic infection spreading trend.

countries with unique approaches towards the management of the pandemic.

### 2.1. A viable approach towards the pandemic

It is essential to understand the pandemic characteristics to frame the strategies for effectively managing the pandemic. In general, the response towards the pandemic can result in two types of infection spreading trends as shown in Fig. 2. When no measures are taken at the appropriate time to prevent or slow down the infection, the type-I trend of infection spread will result. The curve attains the peak very quickly, meaning that the infection is exploding, and the healthcare system would fail miserably to save infected persons leading to an uncontrollable number of deaths. The type-II trend is the best approach for controlling the pandemic as the infected cases are always lesser than the healthcare system's capacity, and this outcome is only possible by developing effective preventive strategies in advance and also implementing them throughout the pandemic period. An apt example of the type-I trend of infection spread has been experienced by the USA and Italy. On the contrary, New Zealand and Australia displayed the type-II infection spreading trend. This particular graph showing the characteristics of pandemic infection spreading trend is significant because it represents the possible impact of the pandemic in a city. Note that the actual infection spreading trend might also occur as a combination of type I and type II depending on the response towards the pandemic. Each type of infection trend can be classified into three phases (from a management perspective) depending on the line of action in dealing with the pandemic from the outbreak of the disease to gaining control over the infection. The first phase focuses on the advanced measures that can be imposed to prevent the ingress of infection into a city and it depicts a pre-pandemic period. The second phase is where the actual pandemic crisis starts and the infection rate rises. The third phase marks the gaining of complete control over the pandemic.

#### 2.1.1. Phase 1 (outbreak or pre-pandemic period)

Phase 1 indicates the time period prior to the emergence of infection in a country or a city from the region of an outbreak. From the past outbreak of the 1918 influenza pandemic and the 2003 SARS outbreak, it is clear that the containment of the borders, international coordination and social distancing methods are the most effective approach (Scientific American, 2020). So, a pre-pandemic period suggests that the outbreak has resulted, and closing the boundaries of the region from the infection hub is the first and foremost preventive measure. The second effective means of action is the proper communication to the public about the current seriousness of the situation to gain cooperation among

them. Then, tracing and monitoring the region of the outbreak will be supportive in analyzing whether some potential persons from the infection hub have already entered the community or not. Only when the source region fails to control the outbreak, it become a threat to humanity. For instance, an outbreak of Nipah virus encephalitis occurred in the Indian state of Kerala as reported in May 2018 (WHO, 2018). With the joint efforts of the health system of Kerala, the government and the people have successfully eradicated the outbreak with just 17 deaths and 18 confirmed cases. In the case of COVID-19, the outbreak emerged in Wuhan, China, as a sudden increase in pneumonia-like infection among the people, which was later identified to be caused by the coronavirus, and the first case was reported on 31 December 2019 (Huang et al., 2020). Though the authorities of the region took immediate actions to close the Wuhan market, the outbreak turned into a pandemic. A study reveals that distance from the epicenter is a strong influential factor and is negatively linked to the COVID-19 spreading pattern (Liu, 2020). In the regions of an outbreak epicenter, rapid diagnosis of the infection to identify the pathogen and reporting the same to the WHO authorities is crucial, and implementing measures for hindering the spreading of infection within that region is pivotal.

In the pre-pandemic period, risk communication and preparing the healthcare system to tackle pandemic inflation are the two predominant factors that eventually help in effectively controlling the pandemic. Risk communication is the key to achieving cooperation among the people (Abrams & Greenhawt, 2020; Zhang, Li, & Chen, 2020). Proper communication of information to the people (transparency) with appropriate awareness and precautionary measures is essential. Moreover, maintaining good relationships between clinical laboratories, government, industries, and healthcare are necessary to control the pandemic (Binnicker, 2020). After some period since an initial outbreak, the information related to the disease involved, ideas of feasible treatment procedures, and infection prevention strategies would have been developed by the concerned authorities. Hence, in response to that, each country can adopt advanced measures and see to their needs to tackle the pandemic.

#### 2.1.2. Phase 2 (Pandemic inflation)

Once the outbreak grows into a pandemic, the probability of spreading of infection to other regions including other countries is more likely to happen except in the case of very strict closure of the country's boundaries. Declaring a nationwide lockdown to slowdown the spread and carrying out vigorous testing followed by contact-tracing of the infected patients are the key measures in phase-2. The spreading of COVID-19 within a region can be classified into four stages of disease transmission (The Weather Channel, 2020) which is as follows:

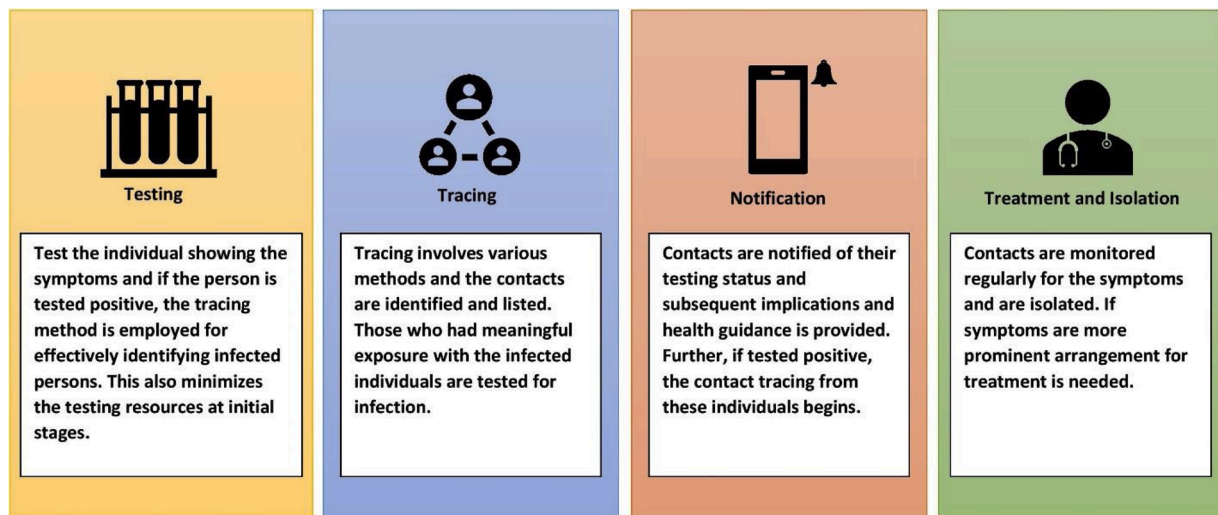


Fig. 3. Relationship among testing, tracing, isolation and treatment.

- Stage 1: Appearance of disease

This stage is marked by the beginning of infection in a region for the very first time. In this stage, only a few people would have been in contact with the virus and its likely spread can be easily traced out with their travel histories to other potentially infected areas.

- Stage 2: Local transmission

The gradual increase in the infected cases indicates the beginning of local transmission. It means that the infection has started to spread from the infected persons to their family, friends, neighbors and other contacted persons. Up to this stage, the infection can be traced and isolated.

- Stage 3: Community transmission

This is the stage where the number of infected cases rises exponentially and is known as community transmission. Newly infected patients will start to appear anywhere in the region such that the infection cannot be traced out. In this stage, it becomes difficult to control and contain the disease. The number of deaths will also start to increase in this stage.

- Stage 4: Epidemic outbreak

This is the worst stage of disease transmission in which the spreading will be rapidly increasing, and deaths will be multiplying in no time. This might ultimately pave the way for the endemic crisis in the infected regions.

The first and foremost thing that one should do in phase 2 is to map a big picture of what stage of disease transmission that currently exists. This can be done only through vigorous testing across the affected region. Concerning the testing methods, the most common and accurate test used is the PCR test, specifically the Real-time Reverse transcription polymerase chain reaction (RT-PCR) test, which mainly detects the viral RNA. Serological or antibody testing is also a widely employed methodology that can detect the antibodies that are generated in response to the virus. Apart from these testing methods, lateral flow assay and antigen testing are prevailing (Verdict Medical devices, 2020). However, WHO does not recommend immunodiagnostic tests such as rapid antigen testing and rapid host antibody detection but encourages to use the latter methodology of testing for fulfilling the disease surveillance requirements (WHO, 2020b). On analyzing the characteristics of various commonly used testing methods, only the PCR tests are highly accurate but are time-consuming, while the serological tests are less accurate but

can be rapidly tested (Schoy et al., 2020). Therefore, different methods will be helpful in different scenarios. For instance, in a highly infected region, say a stage 3 type of spreading, contact tracing becomes ineffective and large-scale testing is required to implement the necessary control measures. For such a case, testing can be carried out in two stages; in the first stage, rapid tests can be employed, and those whose results are positive need to be isolated. Then, those who are tested negative under the rapid tests can be subjected to PCR tests, and accurate diagnosis can be obtained. This type of approach will give an accurate picture of infection in a city and is cost-effective as the rapid test kits (inexpensive) eliminate half of the testing burden for the PCR test (comparatively expensive). On the other hand, technological-based screening is more sensitive than PCR in certain cases, such as CT scans. But a CT scan does not add any diagnostic value in terms of coronavirus as many other pathogens can also result in similar images in the CT scans. CT scans can be effective only when the disease prevalence is high, and the positive results just indicate the higher pre-test possibility of the disease (Hope, Raptis, Shah, Hammer, & Henry, 2020). Fig. 3 shows the relationship among the processes of testing, tracing, isolating and treatment.

On par with testing, another crucial approach to map the infection is the tracing process. Different means of tracing are already in action, such as face-to-face interviewing, telephonic interviews, tracing phone calls, usage of apps assisted by GPS (Global Positioning System), and Bluetooth technologies (Centers of Disease Control & Prevention, 2020; The Wire, 2020). At the initial stages of infection, tracing is critical because an effective tracing can help in maintaining the infection spread under control. Testing and tracing will work co-jointly as the positive tested cases need to be contact-traced while the traced individuals need to be tested for confirmation and the chain of prevention strategy goes on in this phase of the pandemic. As the infection advances from one stage of spreading to the other, the tracing becomes more tedious, and its effectiveness becomes lesser. Large-scale testing is the methodology that needs to be focused on in the case of community spread. Thus, the effective approach requires a balancing shift from far-reaching tracing to extensive testing as the spreading of infection increases.

Thus, in the pandemic inflation period, the infection is more likely to increase and the primary importance should be given to slow down the rate of rising infection. Many factors influence this process such as governmental orders (lockdown), hospital preparedness in treatment and handling of patients, public cooperation and behavior in terms of maintaining social distancing and following other preventive measures, and the extent of testing and tracing of infected individuals (Shaw, Kim, & Hua, 2020). Among these factors, testing and tracing methods are the

only parameters that can be managed to gain control over the situation. Indeed, governmental support is utmost in this period and, if the lockdowns are effectuated early, it can help a lot in mitigating the spread.

2.1.3. Phase 3 (Flatten the curve)

The phrase “flatten the curve” expresses the need to reduce the slope of the cumulative infection curve to zero. In other words, the flattened curve indicates that the infection is controlled as no new infection is reported. Phase 3 is marked by consistent decreases in the active cases. On reaching this phase, the healthcare system would be clear about the best treatment methods, medicines that can be used, and how to handle the patients. Still, continuous health care provision is needed to ensure that the infected individuals completely recover (WHO, 2009). In this phase, the primary target is to maintain the consistency of the decreasing trend in the active cases. Divide and conquer is the effective approach in this phase as different regions in a country might be experiencing different levels of infection. The most infected regions need to be identified and marked as containment zones for repeating the measures taken in phase 2 and have to be isolated from neighboring societies. In the less infected regions, tracing should be performed and the people can enjoy their freedom partially by following social distancing. Thus, a decentralized approach with region-specific methodologies to suppress the spread would ultimately help in overcoming the pandemic. Table 1 states the roles of state and federal governments during a pandemic.

2.1.4. Infection zoning

The plans for resuming all the activities in the city should be

implemented at the end of the pandemic. Before implementation, careful assessment of the region is required to know the infection potential for spreading further. Based on the regional infection trend, an area can be designated as either a liberal zone or a surveillance zone, or an infected zone.

**Liberal zone:** It indicates that the zone is free of infection and it is important to make sure that new cases don't emerge, or else it might eventually lead to community spread and consequently, the second wave of infection. All mobility within the region can be allowed without any time restrictions, while business units, industries, and other usual activities can be permitted to function with precautionary measures. Public transportation can remain suspended and the place where more people gather should be avoided and mobility to other zones except another liberal zone is highly restrained without any approval. All suspended activities and places can function after seeing a consistent record of nil cases for a month.

**Surveillance zone:** If a region shows a progressive decrease in the number of active cases for 2-3 weeks and if the reported new infected cases were also able to be traced back to already infected individuals, then the region can be declared a surveillance zone. The prime motto in the surveillance zone is that concerted efforts should be applied to ensure that the infection decreases consistently, all the way to zero. Intense surveillance is required in this zone so as to prevent the infected persons from interacting with healthy individuals. Restrictions can be eased for operating industries and retail businesses with operating time restrictions (e.g., only 8 hours of operation) and social distancing measures. Apart from these, people's mobility can be limited with night curfews, and these restrictions can be flexible in nature in the

**Table 1**  
Roles of state and federal governments during the pandemic.

Domain	State Government	Federal Government
<b>Risk Communication</b>	<ul style="list-style-type: none"> <li>• Circulate the updated risk messages, policies, strategies and ensure transparency</li> <li>• Disseminate the updated information regarding infection and testing</li> <li>• Provide regular updates to partners, stakeholders, and experts</li> <li>• Ensure the awareness regarding the preventive measures are reverberating from all corners</li> </ul>	<ul style="list-style-type: none"> <li>• Circulate the updated risk messages, policies, strategies and ensure transparency</li> <li>• Disseminate the updated information regarding infection and testing</li> <li>• Provide regular updates to partners, stakeholders, and experts</li> </ul>
<b>Healthcare System</b>	<ul style="list-style-type: none"> <li>• Monitor and satisfy all the demands of healthcare needs</li> <li>• Arrange for extended healthcare facilities if needed</li> <li>• Educate the healthcare workers and cleaners to handle the infected persons</li> <li>• Arrange for mortuary places in case of mass mortality</li> <li>• Ensure continuous supplies of PPE and medicines</li> </ul>	<ul style="list-style-type: none"> <li>• Form an expertise team to analyze, frame the treatment procedures, and monitor the same</li> <li>• Allocate sufficient fund towards the healthcare</li> <li>• Monitor the strain on the healthcare system and provide key medical resources and tools, as needed</li> <li>• Modify and update the measures to be implemented according to the situational needs</li> </ul>
<b>Laboratory and research</b>	<ul style="list-style-type: none"> <li>• Provide required testing kits and equipment</li> <li>• Extend the laboratory services for testing in case of a populous nation</li> <li>• Coordinate regions and localities to effectively collect and test the samples</li> </ul>	<ul style="list-style-type: none"> <li>• Define standards for testing with the experts</li> <li>• Support research on monitoring the virus characteristics</li> <li>• Allocate funds for the development of vaccines and drugs</li> <li>• Distribute critical supplies to state governments and order in mass quantities if needed</li> <li>• Ensure that state governments are in line with the testing approaches</li> </ul>
<b>Infection surveillance</b>	<ul style="list-style-type: none"> <li>• Framing effective tracing methods and implementing the same collectively</li> <li>• Isolating asymptomatic patients and monitoring them</li> <li>• Coordinate partnerships with local agencies to address the issues in case of community spread</li> </ul>	<ul style="list-style-type: none"> <li>• Creating technology-based tracing methods with secure platforms with the guidance of the experts</li> <li>• Evaluate the effectiveness of the measures implemented</li> <li>• Monitor the state governments and assist them in all aspects</li> </ul>
<b>Infection mitigation measures</b>	<ul style="list-style-type: none"> <li>• Monitor the infection status at the regional level and act accordingly</li> <li>• Quarantine the region of infection and perform vigorous testing backed up by tracing methods</li> <li>• Ensure people follow social distancing strategies and other precautionary measures</li> </ul>	<ul style="list-style-type: none"> <li>• Closing the borders step by step and screening the individuals entering the border and asking them to quarantine for two weeks</li> <li>• Imposing nationwide lockdown with the rise in the infection as early as possible</li> <li>• Extending the lockdown and framing the relaxation of lockdown in containment and non-containment zones</li> <li>• Formulating the post-pandemic strategies for a quick recovery of the economy</li> </ul>

**Table 2**  
Various stages in vaccine development as of January 2021 (Centers of Disease Control & Prevention, 2014; WHO, 2020e).

Stages	Sub-stages	Description	Number of vaccines
<b>Exploratory Stage</b>	-	Laboratory research to find potential antigens that can help in preventing or treating the disease	Many vaccines across the globe
<b>Pre-clinical stage</b>	-	Involves cell-culture systems and animal testing to assess the developed vaccine in terms of safety and immunogenicity. Mice and monkeys are the potential animals subjected to testing	177
<b>Clinical development</b>	Phase I	The vaccine is tested on a small group of people	Phase 1: 19 Phase 1/2: 19
	Phase II	The clinical study is expanded and hundreds of people are tested and some may belong to the groups at risk of acquiring the disease	Phase 2: 5 Phase 2/3: 6
	Phase III	The vaccine is given to thousands of people and tested for efficacy and safety	16
	Phase IV	The manufacturer may continue to test the vaccine for safety, efficacy, and other potential uses	-

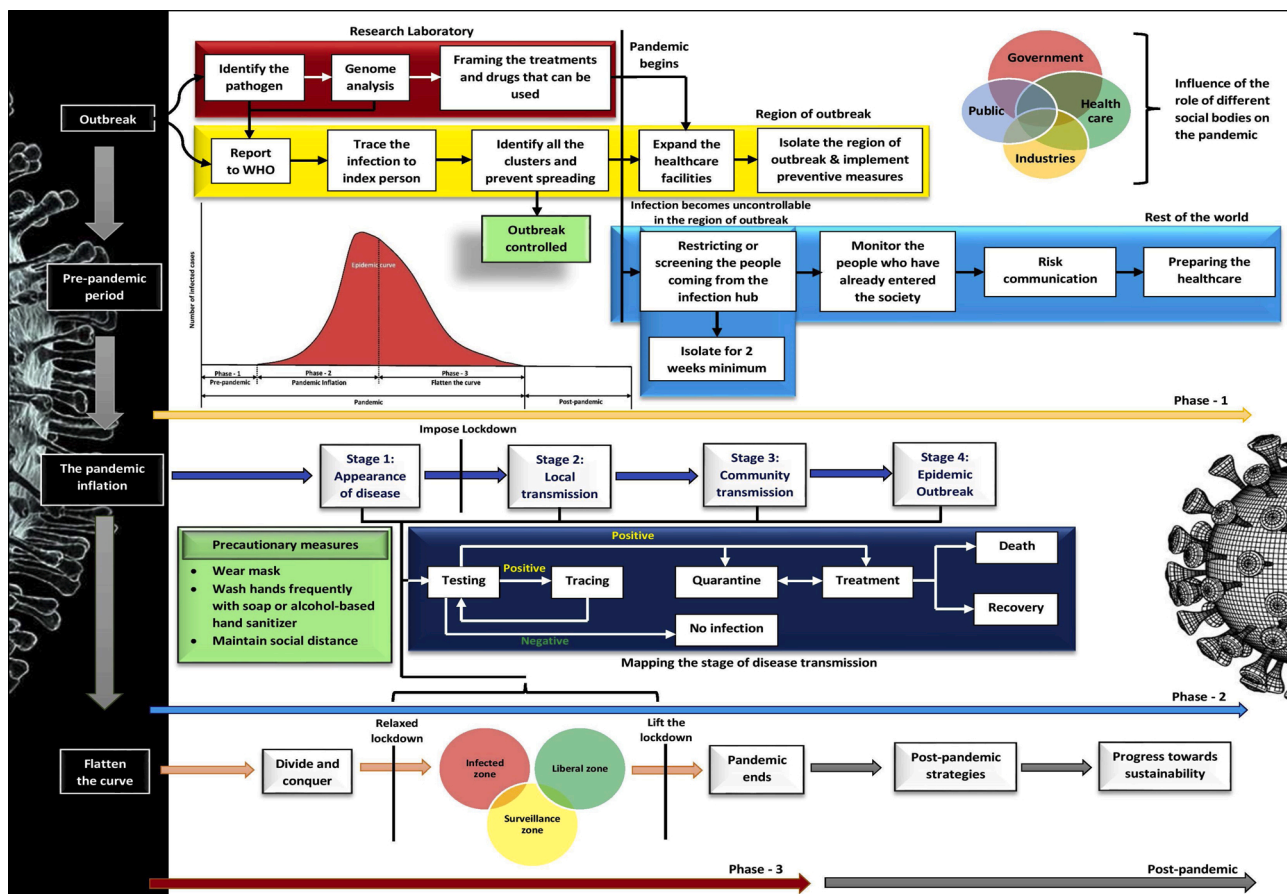
surveillance zone depending on the trend of daily reported infections.  
**Infected zone:** This is the region where the infection is spreading or rising and a greater number of infected individuals prevail. Irrespective of the level of infection spread, the 3Ts (Testing, Tracing, Treatment) and isolation and lockdown have to be imposed to gain control over the spread. Stringent lockdown measures are needed and relaxation of the

restrictions shall be avoided. Inter-zone travel should be strictly prohibited and vigorous testing is pivotal.

**2.1.5. Role of treatment drugs and vaccines**

In general, to overcome the COVID-19 pandemic, three possible ways exist. The first solution is to go through all phases of the pandemic until all the infection disappears, as was the scenario before the pandemic. Secondly, the discovery of an effective treatment drug will make the disease less severe, and finally, the invention of a vaccine will eradicate the virus provided that it doesn't evolve as a new mutant coronavirus for which the vaccine might become ineffective. But there is neither a drug-based cure nor an official vaccine for the novel coronavirus (as of December 2020). While the treatment drugs are being explored and researched for its effectiveness towards the coronavirus, repurposing of existing drugs towards COVID-19 treatment was assessed. As a result of which certain drugs such as hydroxychloroquine, Oseltamivir, Ribavirin and many other drugs have emerged as a potential drug and hydroxychloroquine had been extensively used to treat COVID-19 (Abd El-Aziz & Stockand, 2020; Pawar, 2020; Tripathy, Dassarma, Roy, Chabalala, & Matsabisa, 2020). However, WHO no longer recommends the use of hydroxychloroquine and lopinavir/ritonavir for the treatment of COVID-19 after the analysis resulted in WHO summit on COVID-19 research and innovation (WHO, 2020d). The development of a vaccine is not an easy task. Though a potential vaccine could make the virus inactive in laboratory tests, there are other numerous stages that the same drug should pass only after which it will enter the human phase of testing. The various stages in vaccine development are shown in Table 2. Typically, vaccine development would consume years, but some reports claim that, with the current progress, the vaccine might be developed within 18 months for COVID-19 (The New York Times, 2020a).

The entire process involved in a typical pandemic management is



**Fig. 4.** Schematic representation of a typical pandemic management.



**Table 3**

The response of various countries in COVID-19 pandemic management [as of December 2020]. (Infection status data – WHO, 2020a; Tests per million data – Worldometer, 2020).

Country	Cumulative infected cases	Cumulative death cases	Transmission classification	Tests per million of population	Technology oriented tracking system implemented		Unique measures	Lessons learned	References
					Category	Functionality			
Australia	28,296	908	Sporadic cases	519,697	App (COVIDSafe)	Contact-tracing	Digital contact-tracing methods, National COVID-19 coordination commission, Human Biosecurity emergency	Progressive increase in travel ban restriction, enforcing strict lockdown, extensive testing together with vigorous tracing with the aid of technology can ultimately defeat the spread. As a whole, consistent effort since the emergence of infection is needed to tackle the pandemic	(Australian Government, 2020)
China	96,324	4,777	Clusters of cases	111,163	App (Alipay Health Code)	Contact-tracing, Allots health color code to individuals	Rapid response by building new medical infrastructure and helped other countries in combating the virus	Need to report the outbreak immediately to the WHO and analyze the pathogen to find a methodology to effectively vitiate it. Expanding the medical infrastructure and following the preventive measures is highly helpful. Preventing the people traveling from the outbreak area is necessary to contain the disease within the outbreak region	(Business Insider, 2020; BBC, 2020a; The New York Times, 2020b)
France	2,507,532	62,197	Community transmission	715,275	App (StopCovid)	Contact-tracing	Digital method to trace the infected individuals	Avoid annual gathering events irrespective of importance, postpone elections for the betterment of humanity. Public gatherings make the tracing very difficult	(BBC, 2020b; The Washington Post, 2020b)
Germany	1,640,858	29,778	Clusters of cases	484,895	App (Corona Data Donation)	Monitor the infection, tracing	Overall effectiveness is good in implementing the measures as it is reflected in lesser number of deaths comparatively	Must not under-estimate any pathogen especially when it turns out to be an outbreak. The sooner the implementation of lockdown, the lesser the infection has the potential to spread. Imposing huge fines also helps in persuading the people to follow the restrictions	(Robert Koch Institute, 2020)
India	10,187,850	147,622	Clusters of cases	145,437	App (Aarogya Setu)	Contact-tracing	The nation wide lockdown was imposed in spite of fewer infected cases initially. Easing the export of medicine to other countries	Public cooperation in all aspects is of utmost. Relaxed Lockdown will be of no use and stringent measures should be imposed in the containment zones. Vigorous testing is crucial in populous countries and awareness also plays a role in bringing cooperation in combating the pandemic	(The Print, 2020; The Week, 2020)
Iran	1,194,963	54,574	Community transmission	114,869	App (AC19)	Location-based diagnosis app	Good preparations and managed to contain the infection despite the lack of funds	Earlier lift of lockdown must be avoided until the pandemic is well under control. The lack of public cooperation in maintaining the social distancing and following the preventive measures will ultimately increase the infection	(MIT Technology Review, 2020a)
Italy	2,038,759	71,620	Clusters of cases	571,236	App (Immuni)	COVID community alert	Best healthcare efforts and extensive testing	Public gatherings, sports events are some of the main hotspots where the infection can be traced back. Avoiding public gathering is vital and lockdown measures should be implemented as the infection begins to rise	(Anadolu Agency, 2020; AP News, 2020a)
New Zealand	1,788	25	Clusters of cases	312,890	App (NZ COVID Tracer)	Contact-tracing	Canceled every public gathering event, widest-ranging and toughest border restrictions	Tightening the restrictions stage by stage as of shifting gears in the car at the right time has resulted in an excellent performance in fighting against the pandemic. Less infected cases, very lower number of deaths, and effective approaches towards people were the outcomes of the measures taken	(The Guardian, 2020b)

(continued on next page)

Table 3 (continued)

Country	Cumulative infected cases	Cumulative death cases	Transmission classification	Tests per million of population	Technology oriented tracking system implemented		Unique measures	Lessons learned	References
					Category	Functionality			
Singapore	58,519	29	Sporadic cases	1,115,486	App (Trace Together)	Contact-tracing	Very low deaths for such number of confirmed cases indicating effective handling of infected persons	Response to the pandemic such as imposing the lockdown must be as early as possible. Technology can help in mitigating the spread indirectly. Testing is the key to control the pandemic. Public involvement and cooperation in following preventive measures is vital.	(Singapore Government Agency, 2020)
South Korea	56,872	808	Clusters of cases	116,722	Mapping	Tracks individuals phone data to create a map to show the regions of infected persons	Ground breaking tracing methods in all possible aspects from interviewing to tracking phone data, credit card data	One of the largest and best-organized epidemic control. Established various methods to screen the people. The cycle of testing, extensive tracing, isolating the infected person and quarantining those who contacted the infected person is perfectly carried out to control the pandemic.	(Elkong, Chukwu, & Chukwu, 2020)
USA	18,648,989	328,014	Community transmission	979,909	App (Private Kit: Safe Paths)	Contact-tracing	The rapid response through large quantities of testing and tracing through the infection has peaked in the USA	Underestimation of the pandemic should be avoided. Lockdown is vital and is the only weapon that ultimately directs towards victory or else community spread will result	(AP News, 2020a, 2020b; The Washington Post, 2020a)

presented in Fig. 4. This figure is presented as a timeline process from left to right under each phase of the pandemic and summarizes Section 2.1. Phase - 1 is elaborated from two perspectives: the region of an outbreak and the rest of the world, where the responses vary widely. Phase - 2 is effectuated when the infection is rising steadily and the various preventive measures are illustrated systematically. The most-appropriate period for imposing lockdown, relaxation and lifting of lockdown is also highlighted in Fig. 4.

2.2. Heuristic approaches towards the pandemic by various countries

In this section, the unique measures, learned lessons, the extent of testing, and tracing methods are formulated for 11 countries and is represented in Table 3. These 11 countries are selected based on the responses of various countries towards the pandemic in each phase in terms of effectiveness and also, based on special cases. The criteria under which the selected 11 countries can be categorized is as follows:

- Outbreak region: China
- Phase 1 ineffective: Italy, Germany
- Phase 1 & 2 ineffective: USA
- Phase 3 ineffective: Iran
- Phase 1 effective but Phase 2 ineffective: India
- All three phases effectively controlled: Australia, New Zealand
- Special case: Singapore (Least death to infected case ratio); France and South Korea (Second wave of infection).

In other words, the countries are selected from the nature of the epidemiological curve. The authors claim that every remaining infected country can be more or less be related to the presented 11 countries in terms of their response to the pandemic. In certain categories, two examples are presented since the lesson learned or unique measures implemented might be different comparatively.

3. Technology – A weapon to end the pandemic

As we progress through this information era, technology has an edge in every activity we perform. From entertainment to education, for easy life to healthy life, from becoming smarter to intelligent, on mobility to mobile phones, technology is the backbone that also welcomes you to the digital world. When comparing the past pandemic experience to the current, technological advancement has assisted in enhancing the response to the pandemic in numerous ways. Therefore, revealing the role of technologies during the pandemic crisis will help us to know its influence on minimizing the pandemic impacts. Fig. 5 represents the technological influence during the period of pandemic and in the post-pandemic period. In this figure, the technological support for effective management of pandemic is discussed in Section 3.1 while the technological role in the rest of the pipelines during the pandemic is elaborated in Section 3.2.

3.1. The technological endowment to the pandemic management

The various role of technologies in aiding the pandemic management is elucidated in this section.

3.1.1. Seamless communication and connectivity

Under the pandemic situation, social media have an invisible role in creating awareness among the people and gathering cooperation. Risk perception analysis is an important criterion in the pandemic period and even social media has had an influence on it (Karasneh et al., 2020). At the same time, false information can create considerable trouble among the public and tech giants are taking actions against it. For example, in WhatsApp, the feature of forwarding the messages to many members simultaneously has been reduced to one person at a time (The Verge, 2020). Further, it is possible to influence the citizens

through governmental stratagems in social media, and an investigation on the same is presented in several studies (Chen et al., 2020; Limaye et al., 2020). Apart from these, connectivity supports experts to remotely connect with each other and work on a single goal irrespective of the field of the experts (Luc et al., 2020).

3.1.2. Easy and healthy life

In a pandemic like situation, to follow the quarantine and also to work simultaneously, the work from home approach prevails as the solution which is backed up with multiple technologies (Kramer & Kramer, 2020). Further, with the same context, to make it possible for students to continue their learning, distance learning approaches are more appealing with the developments in the technology. Concerning the health sector, the pandemic caused healthcare units to be flooded with patients, and some individuals might not have been able to consult regarding their medical problems apart from COVID. Such problems are able to be minimized with the role of telehealth facilities, and even online consultations have emerged (Al-Jabir et al., 2020; Hakim, Kellish, Atabek, Spitz, & Hong, 2020). Further, online shopping, food delivery, and cab booking have made our life a lot easier. To the advanced level, the emerging technology of voice assistants such as Google Assistant and Alexa are getting greater attention and have an immense potential to play in the near-future. The role of technologies can also be used to track the residences with infected persons to dispose their waste through proper waste handling systems. For instance, municipal waste collection services can be modified during the pandemic to collect the waste of infected residents separately and not blending them with the other residential waste.

3.1.3. Mobile technology and technology in mobility

Mostly, smartphones prevailed as an entertainment device in the period of the pandemic for reading E-books, surfing the internet, playing games, using social media, and the like. Mobile applications are predominantly helpful in fighting the pandemic in an indirect way (Iyengar, Upadhyaya, Vaishya, & Jain, 2020). Tracing apps played a vital role and even helped governments to a certain extent in tracing the infection quite effectively (BBC, 2020c; Gadgets 360, 2020). Regarding the issue

of mobility, GPS technology is the most widely used aid. Though they have been used to assist people in finding directions to the target place, in a pandemic situation they might be used to track individuals. On the other hand, with the aid of mobility and healthcare data, a study analyzed the potential of data-driven technology in simulating the dynamicity of lockdown measures so as to implement them in an optimized way that will reduce the economic impact (Rahman, Zaman et al., 2020).

3.1.4. Digitalization – the core of the information era

Digitalization has changed the meaning of productivity in most industries and it will continue to influence the industrial sector as Industry 4.0 unfolds (Ribeiro da Silva, Shinohara, de Lima, Angelis, & Machado, 2019; Schumacher, Nemeth, & Sihm, 2019). The vital applications that are developed as a result of digitalization include online payment methodologies, net banking and filling online forms. These have almost eradicated the long queues for service and are user friendly. In the context of the pandemic, they are supportive in numerous ways. First and foremost, the hardcopy forms containing the information is digitalized and, in the health sector for instance, the Electronic Health Record (EHR) is and will be useful in performing analysis of patient clinical data in all aspects which is highly beneficial in any decision-making process and also for other healthcare activities like diagnosis and treatment processes (Garcelon, Burgun, Salomon, & Neuraz, 2020; Jedwab, Chalmers, Dobroff, & Redley, 2019; Kapoor, Guha, Kanti Das, Goswami, & Yadav, 2020; VanLangen, Elder, Young, & Sohn, 2020). As the lockdowns prevail, the needs of processing payment of normal day-to-day purchases have become a lot easier through digital payment methods. On the other hand, even journal manuscripts are empowered with Digital Object Identifier (DOI) number for easy identification in the digital journal platform. Because of this, it is much easier for the researchers working on developing the drugs and vaccines against the coronavirus to check references. As a whole, digitalization has helped to convert the long process into an elemental one without which there would exist possibilities for people exposing to the external environment more frequently to satisfy their daily needs and perform many activities, which means lesser chances to control the spread.

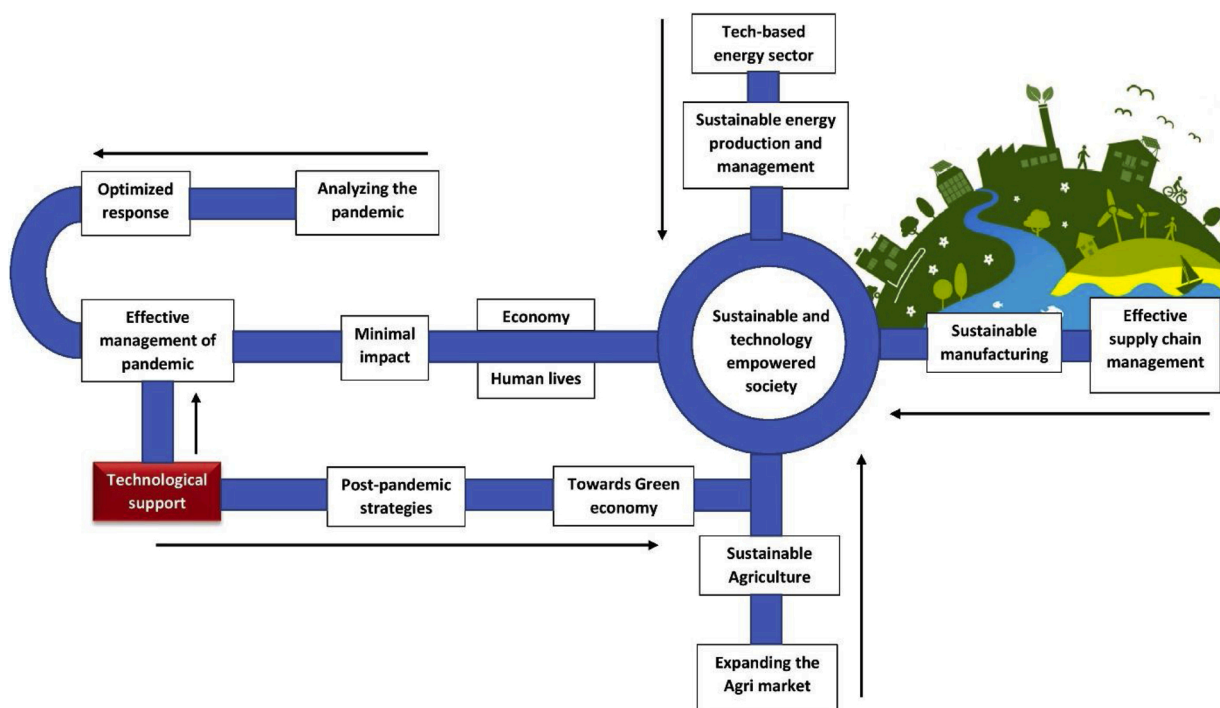


Fig. 5. Mapping the role of technologies to direct the cities and societies in sustainable pathways.

### 3.1.5. Security and Surveillance

Various technologies have widened the term security with the evolution of digitalization as safe and secure gateways, software, and encrypted data is needed to prevent loss of the multidimensional identity of the user. Regarding surveillance, different technologies are aiding in achieving the requirements such as CCTV cameras, drone surveillance, social network analysis, and telephonic surveillance. Deep-learning based monitoring framework can also be utilized for tracking social distance among people (Ahmed, Ahmad, Rodrigues, Jeon, & Din, 2021). In the pandemic, surveillance is much needed in terms of ensuring strict lockdown, disinfecting the area, tracking of infected people, and public health surveillance. Smart technologies with human interactions are also helpful in performing extensive active infection surveillance (Kummitha, 2020).

### 3.1.6. De-emphasized priority for AI, ML & IoT – A pandemic view

Artificial Intelligence (AI) and Machine Learning (ML) are the two tools that changed the perspective of technologies and are the driving development of digitalization. In a pandemic situation, their usage can be put forward as prediction, classification, diagnosis, treatment, and other aspects (Madurai Elavarasan & Pugazhendhi, 2020; Vaishya, Javaid, Khan, & Haleem, 2020). Prediction is employed for determining the outbreak and estimating roughly how many people might be infected in a given region for a given model. For instance, reports suggest that the BlueDot (an AI powered infection-surveillance system-based company) has detected an abnormal rise in pneumonia cases in Wuhan, China and it warned of the outbreak before it has officially announced as a pandemic (Diginomica, 2020). The whole point of prediction is to take early measures to prevent the occurrence of a disaster. In context with it, many practical applications for forecasting the COVID-19 infected status data and the reliability of various deep-learning algorithms are explored in a study (Devaraj et al., 2021). Data classification is another field in which AI and ML are advancing rapidly and it helps us to interpret given clusters of data more easily. In a pandemic, the classification of patients according to their vulnerability to the disease from the provided patient data can be achieved with the use of these technologies (Jiang et al., 2020). Diagnosis is a special field of AI and a clinical screening tool for COVID-19 based on the radiographical changes in the CT scan images has been developed through a deep-learning method (ITN, 2020; Wang et al., 2020). Despite using thermal scanners or taking surveys of the air passengers returning from the infected region, AI-based screening systems would give reliability in the decision making when scrutinizing the infected individuals. For example, the CT scans possess good sensitivity towards lung diseases and, if the radiographical changes are more pronounced, then the person has an increased probability of being infected with COVID-19 when compared to others, and subsequent testing procedures can be performed to confirm the infection. The potential of AI and ML is not utilized in the field of treatment, but it can be actively involved in tasks such as automatically adjusting the parameters in the ventilators for each patient as it would possibly minimize or eliminate the time spent by the healthcare professionals to do this (Ganzert et al., 2002). Apart from these areas, AI can be useful in creating and updating the research information as and when new research is published regarding COVID-19. In the pandemic situation, such efforts are helpful to support researchers, and several publishers have provided open access to COVID related peer-reviewed articles from numerous reputed journals (MIT Technology Review, 2020b). The IoT is currently a key player in the development of Industry 4.0 and, without IoT, the rapid progress in automation ceases to exist. During the pandemic, some regions have used this technology for effective management of medicinal drugs (Ying, Qian, & Kun, 2020) and also for sophisticated applications that ultimately assist in tackling the pandemic (Javaid et al., 2020; Rahman, Peeri et al., 2020; Singh, Javaid, Haleem, & Suman, 2020; Zhu et al., 2020). It is clear from the above discussion that, although AI and ML technologies can help us, these aren't being given sufficient priorities or opportunities to express their potential. Even the results

achieved by implementing these technologies are not emphasized as one of the influencing factors in making a decision in the current scenario.

## 3.2. Plausible technological role in futuristic nexus society amidst pandemic

It is obvious that technology will continue to develop over the course of time and the development will be more focused on digitalization, improved connectivity among people and within intelligent machines, automation, and unmanned vehicles. So, as a whole, technology is moving towards better efficiency, reliability, effectiveness, and more importantly, an improved optimization. Thus, we interpret several logically reasoned models of different societal key pipelines in various aspects by amplifying the usage of currently available technologies at their center. So, if the pandemic exists in such conditions as defined in the model or scenarios, how well can the pandemic be controlled? In other words, this section gives an insight into how the tackling of the pandemic will be different with the digital technologies implemented at a full-fledged state.

### 3.2.1. Future Energy model and the pandemic

In a society, the energy sector is the first to implement the emerging technologies, and even the research effort is much concentrated regarding the energy systems. At each step, that is from the power generation to the transmission and consumption, there is a possibility of increasing efficiency and also to further optimize the systems (Irfan, Elavarasan, Hao, Feng, & Sailan, 2021; Madurai Elavarasan, Leonpraj, Dheeraj et al., 2021).

The energy model presented can be assessed from different perspectives such as energy generation and consumption, energy supply chain, and the resiliency of the system. Fig. 6 details the proposed future energy model. The main problem is in effectively integrating these sources of energies and the model incorporates a Battery Energy Storage System (BESS) to integrate the generated power from various sources for better optimization and flexibility (Garmabdari, Moghimi, Yang, Gray, & Lu, 2020; Monteiro, Bonaldo, da Silva, & Bretas, 2020).

The Energy Management System (EMS) is crucial in controlling the ratio of the amount of power needed that is generated from the renewables to that from the non-renewables all around the clock and EMS plays a key role in dispatching the power based on the demand and power generation (Ajeigbe, Munda, & Hamam, 2020). The role of digitalization, powered by AI, ML, and deep-learning algorithms can effectively forecast the load demand for the given model with societal energy data together with many influencing factors such as seasonal changes (de Queiroz et al., 2019) and, accordingly, can optimize the generation plants output (Yin et al., 2020). The actual load demand is also fed to the system as feedback data. When any issue arises from any of the generation systems or during maintenance periods, the EMS can satisfy the demand with the thermal units for longer periods and with the battery storage system for shorter periods. Apart from that, EMS can be able to subsidize the effects of sudden voltage upheaval by sending appropriate control signals to the corresponding controlling component. On the other hand, EMS is provided with a resilience system that monitors the health of various key generation equipment and, if any fault occurs, immediate detection and further communication to the authorities or self-repair can be accomplished depending on the issues faced.

The main problem highlighted by the pandemic in the energy sector is the varying demand load as the demand swift occurred from industrial, traction, and commercial load to residential load during lockdowns (Jiang, Van Fan, & Klemeš, 2021; Madurai Elavarasan et al., 2020). The energy grid flexibility assisted with an EMS will help in tackling this problem. Currently, manual interpretation is required to forecast the load depending on the operating load units and the subsequent optimization of generation units is performed. But, in the future scenario, the changes in demand load can be automatically diagnosed and can be



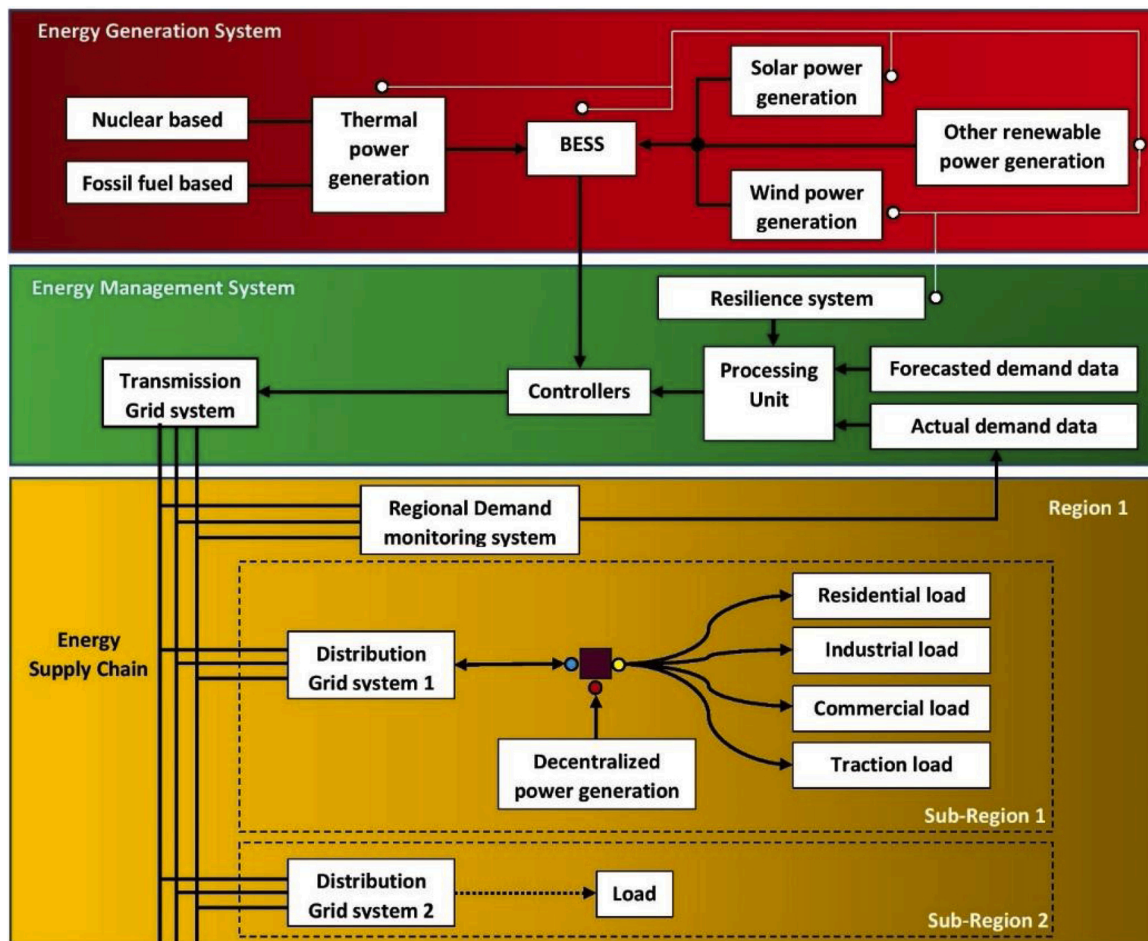


Fig. 6. Schematic illustration of the future energy model.

communicated to the generation units, for operating at high efficiency all the time. On the other hand, if the decentralized system exists in a developed stage, the increase in the residential load can be optimized at each residential unit with their adopted system, meaning that these residential units can be self-sustained in terms of energy. And moreover, the increase in the residential load will not be experienced in the regular grid supply as their energy generation-storage systems can support these fluctuations so that this increase in the demand does not appear as large variations in the grid system. The major limitations of the decentralized demand satisfaction are that they can't support a very high load without significant expansion of the storage system, which requires considerable investment. Further, if any technical issue occurs, the resilience system can immediately detect, diagnose and correct it or report the problem to the concerned authorities. Thus, the time taken in solving the issues will be reduced, and the resilience system provides the signal carrying the information of where the problem occurred and the EMS can effectively manage the power production accordingly. That is why the role of control system architecture such as Supervisory Control and Data Acquisition (SCADA) is very significant (Wertani, Ben Salem, & Lakhoua, 2020). The payment of utility bills is another issue brought out by the pandemic and, as the people are more connected through the internet, the probability of paying the utility bills via an online platform would be increased. Besides, in the case of decentralized power generation systems, there might be some period where residential or industrial premises ultimately produce power to the grid, and the energy sector might have to pay them. Such scenarios can be well managed with the application of energy meters interpreting and balancing the energy consumed from the grid and provided to the grid in terms of cost. Thus, the framing of solutions in such an energy model will become simpler

with the availability of more flexible options. Further, the development in the energy sector of decentralized generation, digitalization (Zhang, Romagnoli, Zhou, & Kraft, 2017), smart grids, and especially the optimization methods would pave the way towards sustainable energy production and management.

### 3.2.2. Supply chain management in a connected world

It can be seen that most of the impact due to the pandemic resulted from the disruption of supply chains and the growing demand cannot be addressed in such scenarios with the industries not getting their supply at the right time. Generally, in the pandemic period, the main supply chains that need to be kept flowing in a city include the industrial, agricultural, and healthcare supply chains. Among these, each supply chain suffers from different issues. The industrial supply chain will be hindered by the non-functioning of raw material industries due to the lockdowns and also with the lack of supply from international supply chains due to a temporary halt in international trade. The agricultural supply chains face market problems as some might be closed due to infection, and alternate markets are needed for selling the yielded crops assuming the logistics are running fine. Among all this, the healthcare supply chain is most significant to combat the infection, and thus, the required products such as ventilators, masks, hand-sanitizer, disinfectants, and personal protective equipment are needed in large quantities. However, one has to consider that these quantities are specifically required only for tackling the coronavirus and, in a future epidemic, a different pathogen may be the root cause and might need different sophisticated products to fight against it, which should also be supported by the industries.

In a futuristic city, we can expect that the automation of industries,

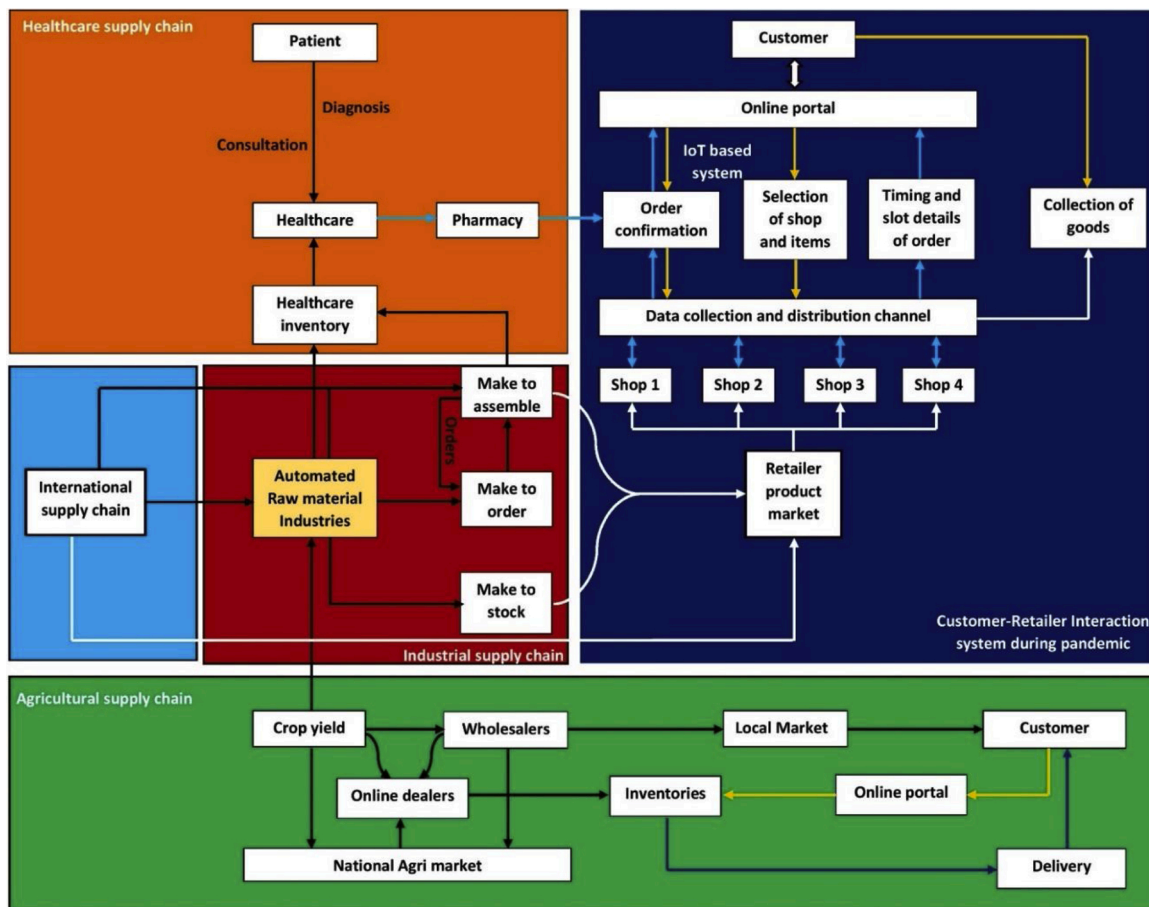


Fig. 7. Schematic illustration of the Supply chain model with customer-retailer interaction system.

increased internet accessibility and connectivity, IoT services, and improved online shopping has flourished. The major assumption in the city is that first and foremost among all the industries, the raw material supplying industries are more focused on increased automation. By doing so, productivity is enhanced, and the supply chain would experience a steady flow of products as it requires less human intervention (Horvat, Kroll, & Jäger, 2019; Sun, Jämsä-Jounela, Todorov, Olivier, & Craig, 2017). Secondly, digitalization is well established within the city. Fig. 7 represents the flow of the product supply chain amidst the pandemic with a sophisticated customer-retailer interaction medium.

During the pandemic period, even if the automated raw material industries are located in the infected region, the manufacturing flow will occur at least at a reduced rate rather than suffering from a complete halt. Further, the decision-making models provide support in optimizing the production lines (Fagundes, Teles, Vieira de Melo, & Freires, 2020; Govindan, Mina, & Alavi, 2020). With a steady supply, the manufacturing industries can plan and cope with the raw materials they receive and with the demand that exists (Production scheduling, 2004). Integrating information systems for the management of supply chains is crucial and it has multi-fold benefits as it can integrate the business process between various suppliers and customers and also provide a solution for information security (Boiko, Shendryk, & Boiko, 2019; de Camargo Fiorini & Jabbour, 2017). Apart from this, the role of intermediaries and logistics are also significant in effective supply chain management (Cole & Aitken, 2020). Sometimes, the international supply chain might be ruptured, and the raw material industry can sustain the flow of products only if their source of the material is within the country. Otherwise the supply chain will be affected. Thus, the industrial supply chain is the heart of the city that can ultimately support every process as shown in Fig. 7, especially during the pandemic period.

Regarding the agricultural supply chain, it can be expected that an online market directly connecting the farmers and the end-users will prevail in the future as such start-ups have already emerged in the current scenario so as to diversify the Agri market (Fielke, Taylor, & Jakku, 2020; Zhou, Cheng, Kang, & Sun, 2018). In a pandemic period, though the markets might not be functioning, as usual, online markets can help in maintaining a steady flow of vegetables, fruits, and other agricultural products to the consumer via an online portal supported by a delivery system.

One important problem faced by the city is ensuring that people follow social distancing. Thus, we propose a system to complete the supply chain with the customer-retailer interaction system, which will ultimately help to follow social distancing by reducing the number of people available at the shop at a given time. A public or private company or even local government can maintain an online portal where the information about the products available from each shop in and near the locality is displayed. The customers can choose whatever available products they need and give their shop preferences and confirm the order. Then multiple time slot options (for example, 10-11 am, 11-12 am) will be provided for the customers to choose according to their schedule, which is required to be confirmed by the customer. After ordering, the shopkeepers will make arrangements for packing the list of things ordered and, at the given slot of time, the customers can come and collect their goods. The slot timings are based on the first-come first-served basis. This will eventually reduce the number of people wandering around the city to make necessary purchases and also help patrol services to function better as they will not need to focus too much on this problem.

In a pandemic period, the healthcare supply chain is crucial and various industries have had to modify their production line to satisfy the

changes in demand. The above method of customer-retailer purchase technique can also be extended into the health sector for purchasing essential medicines from a pharmacy (Ying et al., 2020). In this case, after the patient consults the healthcare system, the list of medicine needed will be digitalized and sent to the customer, after which the customer can edit the details and choose the pharmacy and confirm the order. Then, the procedure for collecting the medicine is the same as mentioned previously. Thus, technology can be used in a much more appealing way to mitigate the spread of infection and, by maintaining the flow of products in the supply chain, the effect of the pandemic on the economy will also be minimized. All these put the industries on the pathway of sustainable manufacturing and support the city in terms of sustainability.

3.2.3. Advanced tracing system

In fighting against the infection during a pandemic, the testing and tracing methods go hand in hand to identify the potentially infected persons and also to confirm the infection. As the technology develops, a more sophisticated technology-empowered tracing system can be built with the existing infrastructure in a future epidemic. A dual role system to alert the people to maintain social distancing and also for tracing is indispensable. Studies suggest that safe social distance ranges between

1.6 and 3 m when aerosol transmission of exhaled droplets is considered (Sun & Zhai, 2020). The proposed tracing system that can possibly help in tracing the individuals relies upon two assumptions. These are that internet accessibility has grown to a greater extent and also that people volunteer to use the tracing app during the pandemic. The app can make use of Bluetooth Low Energy (BLE) or Bluetooth technology (Cabero, Molina, Urteaga, Liberal, & Martín, 2014; Deepika & Usha, 2020; Ho & Chan, 2020; Oosterlinck, Benoit, Baecke, & Van de Weghe, 2017) and can be combined with GPS technology to obtain accurate positioning of the individuals (Li, Wei, Lai, Xu, & Yuan, 2017). Every individual registering in the app will be allocated a unique ID and a family grouping will also be done and a family ID is allocated. For instance, if there are 4 persons living as a family in a house, every person who registers in the app would get a unique ID, and these 4 person’s unique IDs can be grouped under a single-family ID. The main targets of this app are to alert the people when the distance between them is roughly less than one meter and to help the tracing department effectively identify the persons who have possibly come into contact with infected individuals.

The app will start its Bluetooth search only if the person’s GPS position changes drastically, meaning he/she goes out from his/her house. To understand the working, let us consider a scenario that a person goes out for some valid reason and encounters another person without

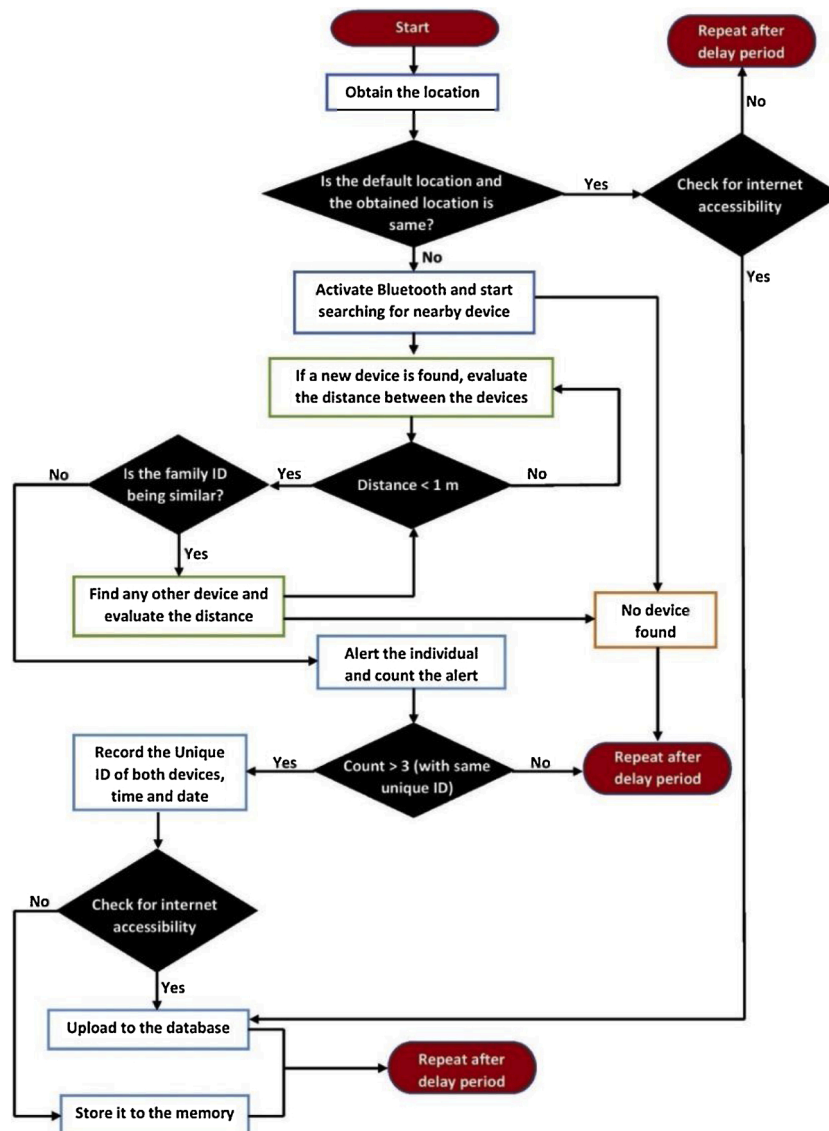


Fig. 8. Flowchart of process involved to alert people to maintain social distance.

maintaining the minimum distance between the individuals. If both have their smartphone installed and registered in the app, then, using the Bluetooth signals, both the devices will detect each other, and a rough distance between them is determined. If it is less than the lower limit distance for a consistent period of time, say 30 seconds, then a warning is provided by means of device vibration indicating to follow the social distance requirement. If the alert is repeated say for three times, it records the date, timing and the unique ID of the involved individuals at both of their respective apps. This recording can be fed to the surveillance database, which can be used by the tracing department later. Internet is required only for uploading the data to the surveillance database; meanwhile, the recording is temporarily stored within the app memory. Another important feature of this app is one can fill the testing form and submit it so that an appointment is provided from the nearby testing facility. The flowchart of the working of this process is demonstrated in Fig. 8.

Regarding the tracing, if a person is tested positive and found to be asymptomatic, then a wearable band is provided to that person so as to isolate himself/herself and it would work on GPS technology. Also, if the person doesn't isolate, the surveillance authorities can find the person from the GPS data stored in the surveillance database. Then, if the person is tested positive and found to be symptomatic, the person's details are sent to the healthcare database to arrange for treatment. Now, in order to trace the individuals who might have possibly been infected, the tracking department can use the surveillance database to extract the information of alerts that have been uploaded from the app of individual persons. From the date of the positive test result to the desired past date, all the alerts involving the unique ID of the infected individual are sorted and the corresponding other persons involved in each alert are sent a notification to isolate themselves as they might have in contact with the infected individual and the notification is also sent to the whole family. To add upon this, the unique ID of the family members can be accessed through the family ID, and the second cycle of tracing can be performed as mentioned above, starting from the family members. If any of these persons exhibit symptoms, he/she can apply for testing and confirm the presence or absence of the disease. This is the overall framework of how the tracing function works and this system can adopt different technologies, but the methodology to identify each person with a unique ID, grouping the family members, providing alertness if social

distancing is not followed, filling of a sample test application form and tracing methods are the characteristics of this coordinated system and will be more effective if more people use the app. Fig. 9 shows the framework of the proposed tracing system.

#### 4. Cleansing the pandemic impacts – The revitalization strategies

The pandemic is a major threat to the development of humanity in numerous ways. If a pandemic occurs, first, it will pose a threat in the form of infection, the first wave of threat. In order to overcome the first wave of threat, a country or a region has to be completely confined from its regular activities to mitigate the spread. Thus, a consequential second wave of threat approaches to the development in the form of economic hardships. Further, the third wave of threat stretches into the future in the form of multiple small drags that greatly affect the individual peoples in different regions at varying intensities. The worst impact includes the economic recession, upheaval of unemployment and pandemic induced rise in the poverty rate. Thus, in this section, the strategies that are required to build a resilient city in the aftermath of a pandemic and also, to sustainably develop the city is elucidated as follows:

- When analyzing the various factors that contributed to the economic recession, supply chain disruption is the prime cause. Enhancing the collaboration and partnerships among various industries, institutions and governmental agencies would minimize the individual efforts needed and also, would simultaneously help them to grow across various dimensions to tackle the impacts caused by the pandemic.
- Reworking value chains and even supply chains based on geolocation apart from the economic criteria alone is needed in the post-pandemic world. This would sustain the continuity in the supply chain provided that the raw materials resource availability supports the geostrategic planning.
- From an industrial risk management point of view, some crucial parameters that can help in enhancing the effectiveness in the supply chain management and also in industrial risk management include enhancing the diversity of interdependence, strengthening the weakest link in the supply chain, establishing back-up plans and immediate responses to the situation, creating a collaborative

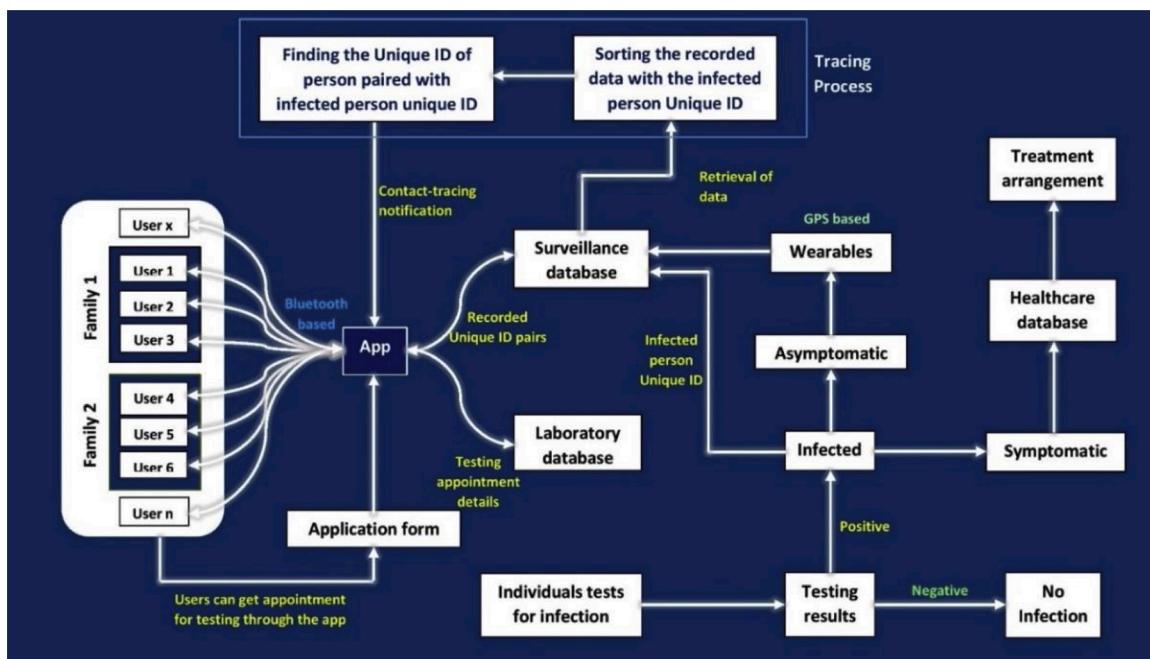


Fig. 9. Framework of the tracing system.



environment with industries and supply chain partners, risk assessment, quantification and management, and flexibility of the organization (Kleindorfer & Saad, 2009; Munir, Jajja, Chatha, & Farooq, 2020).

- Expanding the Agri market is crucial in maintaining the balance between production and consumption. During the pandemic crisis, though the production rate remained constant, wastage of food increased due to the irregular functioning of various societal bodies that procure agricultural products. This prompts the need for an improved agricultural market design that is resilient to supply chain disruption. The digitalization role and technological influence can ultimately act as a foundation to impart sustainability to the agricultural domain. This scenario is well-established in Section 3.2.2.
- Excessive medical and residential waste during the pandemic has severely affected municipal waste management (Irfan, Ahmad et al., 2021) and various patterns of waste proportions in different geological locations have been reported (Van Fan, Jiang, Hemzal, & Klemeš, 2021). The pandemic has completely shifted the focus to avoid single-use plastics, influencing consumer behavior in the post-pandemic period (Sharma et al., 2020). The disposal of PPE should be appropriately directed at the source and should be avoided to mix with the usual waste. Studies suggest the need for a diversified approach to minimize the environmental footprints of PPE's in terms of both production and disposal (Klemeš, Van Fan, & Jiang, 2020). The urgent need to shift the production of fossil-fuel based plastics to bioplastics needs to accomplish and single-use plastic should be avoided altogether (Tripathi, Tyagi, Vivekanand, Bose, & Suthar, 2020). Energy recovery measures from plastic disposal such as through incineration plants should be substantiated.
- The employment scenario in the post-pandemic world would decide the fate of economic growth in the upcoming years. Thus, prioritizing the job security for middle-income and low-income earners is pivotal. On the other hand, work from home has rapidly gained attention in the pandemic period. Many digitalized jobs can be developed by considering work from home strategy, and it prevails as a potential area to explore and innovate new type of jobs.

- The energy transition is the key revitalization strategy to direct the world towards sustainability (IRENA, 2020b). Besides, numerous job opportunities are generated in the progress of energy transition from manufacturing, logistics, installation, operation, and maintenance, where plenty of human resources and skills are required to support the change. This pathway appears more preferable in the post-pandemic world as this would also drive the economy, enhance human welfare and paves the way to mitigate the climate crisis.
- Investments have crucial roles to play in the post-pandemic period. This factor would even influence to an extent such that either a better world or a much worsen world would evolve after the pandemic. Investments are needed to promote the developments that go in hand with the environment, such as sustainable energy production and consumption, green technologies, digitalization, recycling, and efficiency enhancement.
- The current scenario is in need of policies and innovative strategies to impart social security to the poor and vulnerable. Furthermore, as the poverty rate is rising due to pandemic impacts, effective measures need to be planned and framed to mitigate them to the level of 2019. One such approach is linked to how the post-pandemic world sees an increase in employment opportunities. Education and skill are other criteria to classify the job potential of the needy person. And vigorous analysis, as well as implementation measures supported by policies, is needed to change the employment dynamics in which the improvement in the proportion of skilled and unskilled job would, in turn, drive the economy.
- Focusing on the green economy will direct humanity in a sustainable path as it aims to develop an economic system with reduced environmental risk and ecological scarcities. But it needs tremendous efforts from the political side and green premium policies are required to underpinning the green economy.
- The occurrence of pandemics and epidemics are rising mainly due to ecological imbalance powered by deforestation. As humans exploit forest resources and converts them as a society to live, the probability of animals interacting with the society increases and thus, the possibilities of novel disease transmission to humans also increases. To

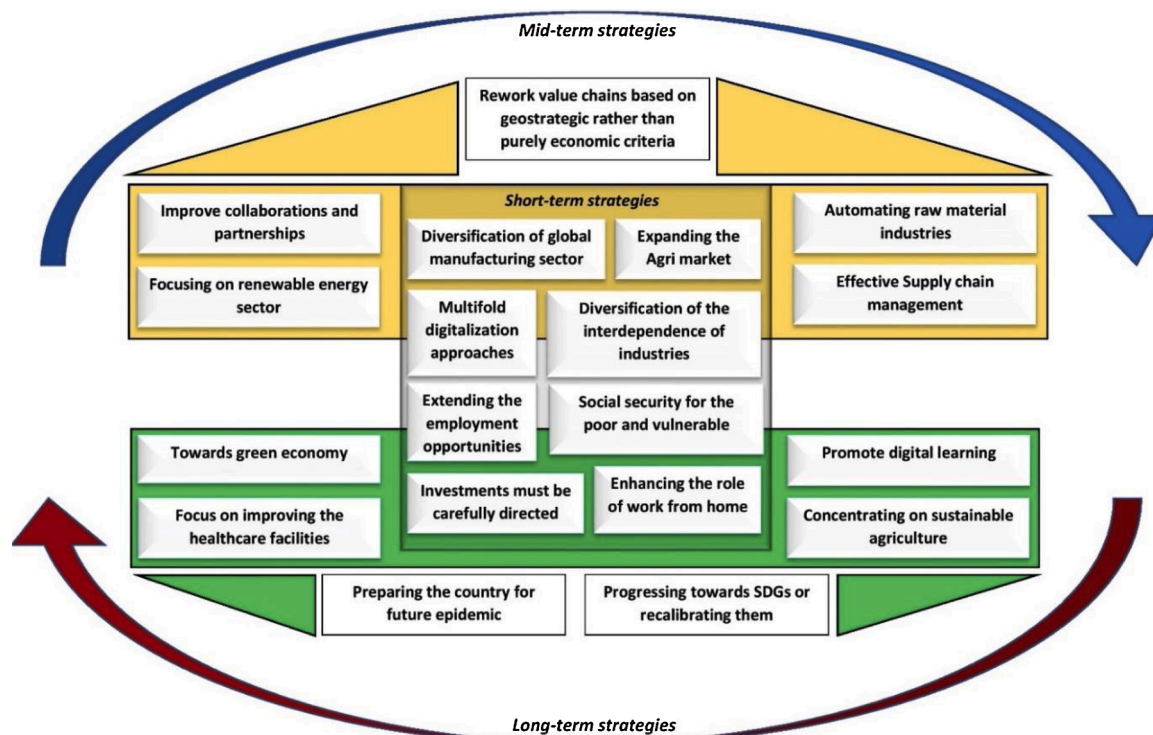


Fig. 10. Post-COVID strategies on the basis of short-term, mid-term and long-term needs.

reverse the effect, humans should pave the way for afforestation, and also the interaction between nature and humans in disease hotspot regions (especially in Asia) should be carefully controlled (Megahed & Ghoneim, 2020; WHO, 2020c).

- When compared to the pandemic, the climate crisis appears much bigger, and even if humans focus on the measures to accelerate the climate actions, then the probability of pandemic occurrence might even get reduced with the gain of ecological balance.
- The effect on 17 Sustainable Development Goals (SDGs) due to the pandemic impacts should be assessed and a refined or recalibrated target is required for vigorous planning and execution. The pandemic clearly demolished the progress in SDG 1 and SDG 8 especially, and strategic planning, international collaborations, and partnerships are required to solve the crisis elegantly.

The post-COVID strategies that a city should focus on the short-term, mid-term and long-term basis are illustrated in Fig. 10. The short-term strategy is coined in context with the priority of need in the city and should be implemented immediately. Investments in the post-pandemic period have crucial roles to play and, thus, carefully directing the investment is a short-term strategy while the strategies such as effective supply chain management, or improving collaborations and partnerships cannot be focused on immediately, but such strategies can be concentrated after the recovery and are depicted as mid-term strategies. On the other hand, long term strategies are the ultimate goal that can be inculcated in each and every strategy that can possibly be implemented. For instance, directing a focus towards the green economy and sustainable development needs consistent efforts on a long-term basis. As a whole, the economy, although under recession, can be put back to its position with as minimum loss as possible with the prompt implementation of various strategies.

##### 5. An indispensable way to sustainable cities in the post-pandemic period: SWOT-Fuzzy TOPSIS analysis

The revitalization strategies provide an insight into where we need to focus for cleansing the pandemic impacts, but the post-pandemic period needs much more comprehensive efforts, which helps in mitigating the impacts as well as directs us right in the pathway of sustainable cities. To identify an indispensable way to sustainable cities from the end of the pandemic, a hybrid methodology, namely, *Strengths Weaknesses Opportunities Threats – Fuzzy Technique for Order of Preference by Similarity to Ideal Solution* (SWOT-Fuzzy TOPSIS) is proposed and incorporated. The SWOT analysis will aid in picturizing the current scenario by means of strengths and weaknesses factor while it also maps the awaiting challenges and available tools to encounter the future scenario through threats and opportunities factor. Fuzzy TOPSIS is a multi-criteria decision analysis method to figure out the best alternatives under a fuzzy environment for the defined scenarios (Lima Junior, Osiro, & Carpinetti, 2014; Zyoud, Kaufmann, Shaheen, Samhan, & Fuchs-Hanusch, 2016). This method yields quality judgements and effectively deals with the uncertainties involved (Beikkhakhian, Javanmardi, Karbasian, & Khayambashi, 2015; Lima Junior et al., 2014) and has been implemented in many real-world practical cases. Fuzzy TOPSIS methodology is already applied in the domains of electric vehicles (Rajak & Shaw, 2019), business (Samaie, Meyar-Naimi, Javadi, & Feshki-Farahani, 2020), environmental analysis (Onu, Quan, Xu, Orji, & Onu, 2017), demand-side management (Madurai Elavarasan, Leoponraj, Vishnu-priyan, Dheeraj, & Gangaram Sundar, 2021) and mobile health application (Wu, Liu, & Liu, 2018). As a whole, this hybrid methodology of the SWOT-Fuzzy TOPSIS approach will highlight the best pathway to deal with the post-pandemic scenario to direct towards sustainable cities. This hybrid approach is also found to be incorporated in the field of planning energy scenarios (Cayir Ervural, Zaim, Demirel, Aydin, & Delen, 2018; Papapostolou, Karakosta, Apostolidis, & Doukas, 2020). The detailed methodology is explained below:

##### Step 1: Identifying SWOT factors

The strength factors are gathered with a notion to find the positive change that the pandemic has created, which would help in making the cities sustainable. The weakness factors are those that are resulted from the occurrence of the pandemic which makes it challenging to make the cities sustainable. The opportunity represents the strategy that can direct us in sustainable pathways and the threat factors represent the major challenge in making the cities sustainable. The factors corresponding to each SWOT criteria (such as strengths, weaknesses, opportunities and threats) are identified through an extensive literature survey, United Nations publications (United Nations, 2020), and interpretation through authors' expertise. The identified factors are then filtered for the most-significant influence and it resulted in five factors in each of four criteria which is presented in Table 4.

##### Step 2: Collect and aggregate linguistic ratings from decision-makers

The linguistic ratings for an opinion or SWOT factor are obtained from three decision-makers (Authors) to mitigate the ambiguity in allocating weightage. Here, the linguistic ratings are provided on the basis of a 5-factor linguistic rating scale that varies from "Very high" to "Very low" to depict an opinion's influence for the considered aspect. The decision-makers need to provide ratings for the SWOT factors based on two different perspectives. One from the ability of the factors to impart resiliency to pandemic impacts (factors belonging to strengths and opportunities) or the ability of the factors to make it challenging to achieve resiliency to pandemic impacts (factors belonging to weaknesses and threats). Another perspective is to provide a rating for the ability of the factors to hasten or hinder the progress for making the cities sustainable. The former perspective is termed as "Revitalization ability" and the latter one is termed as "Sustainability ability" in this analysis. Therefore, each of the SWOT factors (20 factors) is rated for its ability to revitalize the pandemic impacts and direct towards sustainability which is shown in Appendix A Table A1.

##### Step 3: Fuzzy decision matrix

Corresponding to the ratings provided by three decision-makers for every SWOT factors as described in the previous step, the decision matrix is prepared by converting the linguistic ratings into triangular fuzzy numbers (TFN). The 5-factor linguistic rating scale and its equivalent TFN is shown in Table 5. This process of converting linguistic ratings into fuzzy numbers is known as fuzzification and the obtained fuzzy decision matrix of three decision-makers is illustrated in Table 6.

##### Step 4: Combined fuzzy decision matrix

The fuzzy pairwise comparison decision matrix of all the experts are integrated together to build a combined decision matrix. The elements  $X_{ij}$  of the combined decision matrix is calculated by using Eq. (1).

$$x_{ij} = (A_{ij}, B_{ij}, C_{ij}), \text{ where } A_{ij} = \min_k [a_{ij}^k], B_{ij} = \frac{1}{K} \sum_{n=1}^k b_{ij}^n, C_{ij} = \max_k [c_{ij}^k] \quad (1)$$

Where, a,b,c are the components of TFN associated with decision matrix of each experts, A,B,C are the components of TFN corresponding to combined decision matrix, i represents the perspectives (revitalization and sustainability ability) of ratings, j represents the SWOT factors and k is the number of decision makers involved or decision matrix. The combined decision matrix is shown in Table 7.

##### Step 5: Normalized fuzzy decision matrix

The criteria under which the SWOT factors are evaluated can be

**Table 4**  
Identified SWOT factors.

Strengths		Weaknesses	
<b>S1</b>	Improvised healthcare system and hastened technological penetration in the medical field	<b>W1</b>	Catastrophic economic blow and upheaval of urban poverty
<b>S2</b>	Exponential growth in digital services and technologies in the wide range of domains	<b>W2</b>	Fragmented urbanization and deficient slum upgradations measures
<b>S3</b>	Reassessment of the economic model and crisis management ability of cities	<b>W3</b>	A widened gap in social inequalities due to pandemic
<b>S4</b>	Strengthened collaborative efforts from various social bodies and within different levels of governments	<b>W4</b>	Lack of energy-efficient infrastructure and resiliency to climate change
<b>S5</b>	Systematic, reliable, and robust urban data and statistics	<b>W5</b>	Existence of linear economy and less focus on innovative design, planning and management of cities to promote multiple benefits
Opportunities		Threats	
<b>O1</b>	Transition to green energy and reducing energy intensity	<b>T1</b>	Increasing environmental footprint
<b>O2</b>	Nature positive economic development	<b>T2</b>	Information barrier and lack of transparency
<b>O3</b>	Progressing towards smart cities and reskilling the workers for associated employment	<b>T3</b>	Challenges to providing equal urban services and social justice
<b>O4</b>	Healthy urban planning and reduce transportation time within cities	<b>T4</b>	Management of pandemic caused waste and recycling of municipal waste
<b>O5</b>	Improve the financial performance of local government and promote territorial development	<b>T5</b>	Rise of urban population

characterized as cost criteria and benefit criteria. The cost criterion is the one where minimum weightage or importance is desired. Hence, the criteria *revitalization ability* is chosen as cost criteria, and *sustainability ability* is allocated as benefit criteria. Depending on the benefit and cost criteria, the normalization of the decision matrix is accomplished in accordance with Eqs. (2) and (3). Table 7 represents the normalized fuzzy decision matrix.

For benefit criteria,

$$R_{ij} = \left( \frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right), \text{ where } c_j^* = \max_j \{c_{ij}\} \tag{2}$$

For cost criteria,

$$R_{ij} = \left( \frac{a_j^-}{c_{ij}^-}, \frac{a_j^-}{b_{ij}^-}, \frac{a_j^-}{a_{ij}^-} \right), \text{ where } a_j^- = \min_j \{a_{ij}\} \tag{3}$$

**Step 6: Weighted Normalized fuzzy decision matrix**

Since progressing towards sustainability is much significant and represents a long-term goal, the sustainability ability criteria are given more weight than the revitalization ability criteria (Sustainability ability – Very high; Revitalization ability – High). The linguistic ratings provided to the criteria are then converted to equivalent TFN using Table 5. The weighted normalized fuzzy decision matrix is obtained by multiplying the TFN allotted for the criteria (weights based on a 5-factor linguistic rating scale) and its corresponding elements in the normalized fuzzy decision matrix. This is mathematically expressed in Eq. (4).

$$\tilde{V}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_j \tag{4}$$

where,  $\tilde{V}_{ij}$  is the element of weighted normalized fuzzy decision matrix. The weighted normalized fuzzy decision matrix is presented in Table 7.

**Step 7: Evaluate Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS)**

The FPIS maximizes the influence of benefit criteria and minimizes the influence of cost criteria, and FNIS does the opposite (Beikkhakhian et al., 2015). The FPIS and FNIS are represented by  $A^+$  and  $A^-$ , respectively, and is calculated by using Eqs. (5) and (6). The obtained FPIS and FNIS attributes for SWOT factors is shown in Table 8.

$$A^+ = (\tilde{V}_1^+, \tilde{V}_2^+ \dots \tilde{V}_n^+), \text{ where } \tilde{V}_n^+ = \max_j \{ \tilde{V}_{ij}^+ \} \tag{5}$$

$$A^- = (\tilde{V}_1^-, \tilde{V}_2^- \dots \tilde{V}_n^-), \text{ where } \tilde{V}_n^- = \min_j \{ \tilde{V}_{ij}^- \} \tag{6}$$

**Step 8: Compute the distances from FPIS and FNIS**

The separation distance from FPIS and FNIS is calculated by using Eqs. (7)–(10). Table 9 shows the resulted separation distance from FPIS and FNIS.

$$d(\tilde{V}_{ij}, \tilde{V}_j^+) = \sqrt{\frac{1}{3} \left[ (\tilde{V}_{ija} - \tilde{V}_{ja}^+)^2 + (\tilde{V}_{ijb} - \tilde{V}_{jb}^+)^2 + (\tilde{V}_{ijc} - \tilde{V}_{jc}^+)^2 \right]} \tag{7}$$

$$d(\tilde{V}_{ij}, \tilde{V}_j^-) = \sqrt{\frac{1}{3} \left[ (\tilde{V}_{ija} - \tilde{V}_{ja}^-)^2 + (\tilde{V}_{ijb} - \tilde{V}_{jb}^-)^2 + (\tilde{V}_{ijc} - \tilde{V}_{jc}^-)^2 \right]} \tag{8}$$

**Table 5**  
Utilized 5-scale linguistic ratings and the equivalent TFN.

Linguistic ratings	Equivalent TFN
Very high	7,9,9
High	5,7,9
Average	3,5,7
Low	1,3,5
Very low	1,1,3

$$d_i^+ = \sum_{j=1}^n d(\tilde{V}_{ij}, \tilde{V}_j^+) \text{ where, } i = 1, 2, 3, \dots, n \tag{9}$$

$$d_i^- = \sum_{j=1}^n d(\tilde{V}_{ij}, \tilde{V}_j^-) \text{ where, } i = 1, 2, 3, \dots, n \tag{10}$$

**Step 9: Calculate the Closeness coefficient for each factor**

The Closeness coefficient (CC<sub>i</sub>) can be calculated for each SWOT factors by using Eq. (11) and the evaluated CC<sub>i</sub> is represented in Table 9. The CC<sub>i</sub> value of various SWOT factors is plotted in Fig. 11. With this CC<sub>i</sub> value, the ranking of the alternative is accomplished.

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \text{ where, } i = 1, 2, 3, \dots, n \tag{11}$$

**Table 6**  
Fuzzy decision matrix of decision-maker 1 to 3.

SWOT factors	Decision Maker 1						Decision Maker 2						Decision Maker 3					
	Revitalization ability			Sustainability ability			Revitalization ability			Sustainability ability			Revitalization ability			Sustainability ability		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
<b>Strength factors</b>																		
S1	7	9	9	7	9	9	5	7	9	3	5	7	7	9	9	5	7	9
S2	5	7	9	5	7	9	3	5	7	5	7	9	7	9	9	7	9	9
S3	7	9	9	7	9	9	1	3	5	7	9	9	5	7	9	5	7	9
S4	5	7	9	5	7	9	3	5	7	1	3	5	7	9	9	5	7	9
S5	5	7	9	5	7	9	1	1	3	3	5	7	5	7	9	5	7	9
<b>Weakness factors</b>																		
W1	7	9	9	7	9	9	7	9	9	7	9	9	3	5	7	5	7	9
W2	5	7	9	5	7	9	5	7	9	5	7	9	5	7	9	3	5	7
W3	3	5	7	5	7	9	3	5	7	3	5	7	3	5	7	3	5	7
W4	5	7	9	7	9	9	1	3	5	1	3	5	5	7	9	5	7	9
W5	5	7	9	7	9	9	1	1	3	1	1	3	3	5	7	5	7	9
<b>Opportunity factors</b>																		
O1	7	9	9	7	9	9	7	9	9	7	9	9	3	5	7	7	9	9
O2	5	7	9	5	7	9	5	7	9	5	7	9	3	5	7	5	7	9
O3	5	7	9	7	9	9	3	5	7	3	5	7	5	7	9	3	5	7
O4	7	9	9	5	7	9	1	3	5	1	3	5	3	5	7	5	7	9
O5	5	7	9	5	7	9	1	1	3	1	1	3	5	7	9	3	5	7
<b>Threat factors</b>																		
T1	3	5	7	5	7	9	7	9	9	7	9	9	3	5	7	5	7	9
T2	5	7	9	5	7	9	5	7	9	5	7	9	5	7	9	5	7	9
T3	5	7	9	7	9	9	3	5	7	3	5	7	5	7	9	5	7	9
T4	5	7	9	7	9	9	1	3	5	1	3	5	3	5	7	5	7	9
T5	3	5	7	3	5	7	1	1	3	1	1	3	5	7	9	3	5	7

**Step 10: Ranking of the factors**

In this analysis, the ranking is done based on the highest CC<sub>i</sub> value by comparing the CC<sub>i</sub> of each SWOT factors. A separate ranking is allocated under each of the SWOT criteria to highlight the factors that evolves as the best factor to focus under Strengths, Weaknesses, Opportunities and Threats. Table 9 presents the ranking of the SWOT factors.

Therefore, the obtained ranking depicts the factors with higher potential in terms of both revitalization ability and sustainability ability. The results show that the situation that pandemic created to reassess the economic model and improved crisis management ability of the cities will become the biggest strength, lack of energy-efficient infrastructure and resiliency to climate change is the existing major weakness, the best opportunity to utilize in the post-pandemic period to make the cities sustainable would be healthy urban planning and reduce transportation time within cities, and the existing catastrophic threat is the generated pandemic waste and the need for its effective management. The strengths should be utilized sustainably and efforts to minimize the weakness with the prevailing opportunities should be accomplished. The top-threats should be prioritized to prevent their cataclysmic aftermath effects on both environment as well as humanity. All these SWOT factors will ultimately pave the way for sustainable cities.



Table 7

(a) Combined fuzzy decision matrix (b) Normalized fuzzy decision matrix (c) Weighted normalized fuzzy decision matrix.

SWOT factors	(a) Combined fuzzy decision matrix						(b) Normalized fuzzy decision matrix						(c) Weighted normalized fuzzy decision matrix											
	Revitalization ability			Sustainability ability			Revitalization ability			Sustainability ability			Revitalization ability			Sustainability ability								
	High			Very high			5	7	9	7	9	9	5	7	9	7	9	9						
<b>Strength factors</b>													<b>Strength factors</b>						<b>Strength factors</b>					
S1	5	8.33	9	3	7	9	0.11	0.12	0.20	0.33	0.78	1.00	0.56	0.84	1.80	2.33	7.00	9.00						
S2	3	7	9	5	7.67	9	0.11	0.14	0.33	0.56	0.85	1.00	0.56	1.00	3.00	3.89	7.67	9.00						
S3	1	6.33	9	5	8.33	9	0.11	0.16	1.00	0.56	0.93	1.00	0.56	1.11	9.00	3.89	8.33	9.00						
S4	3	7	9	1	5.67	9	0.11	0.14	0.33	0.11	0.63	1.00	0.56	1.00	3.00	0.78	5.67	9.00						
S5	1	5	9	3	6.33	9	0.11	0.20	1.00	0.33	0.70	1.00	0.56	1.40	9.00	2.33	6.33	9.00						
<b>Weakness factors</b>													<b>Weakness factors</b>						<b>Weakness factors</b>					
W1	3	7.67	9	5	8.33	9	0.11	0.13	0.33	0.56	0.93	1.00	0.56	0.91	3.00	3.89	8.33	9.00						
W2	5	7	9	3	6.33	9	0.11	0.14	0.20	0.33	0.70	1.00	0.56	1.00	1.80	2.33	6.33	9.00						
W3	3	5	7	3	5.67	9	0.14	0.20	0.33	0.33	0.63	1.00	0.71	1.40	3.00	2.33	5.67	9.00						
W4	1	5.67	9	1	6.33	9	0.11	0.18	1.00	0.11	0.70	1.00	0.56	1.24	9.00	0.78	6.33	9.00						
W5	1	4.33	9	1	5.67	9	0.11	0.23	1.00	0.11	0.63	1.00	0.56	1.62	9.00	0.78	5.67	9.00						
<b>Opportunity factors</b>													<b>Opportunity factors</b>						<b>Opportunity factors</b>					
O1	3	7.67	9	7	9	9	0.11	0.13	0.33	0.78	1.00	1.00	0.56	0.91	3.00	5.44	9.00	9.00						
O2	3	6.33	9	5	7	9	0.11	0.16	0.33	0.56	0.78	1.00	0.56	1.11	3.00	3.89	7.00	9.00						
O3	3	6.33	9	3	6.33	9	0.11	0.16	0.33	0.33	0.70	1.00	0.56	1.11	3.00	2.33	6.33	9.00						
O4	1	5.67	9	1	5.67	9	0.11	0.18	1.00	0.11	0.63	1.00	0.56	1.24	9.00	0.78	5.67	9.00						
O5	1	5	9	1	4.33	9	0.11	0.20	1.00	0.11	0.48	1.00	0.56	1.40	9.00	0.78	4.33	9.00						
<b>Threat factors</b>													<b>Threat factors</b>						<b>Threat factors</b>					
T1	3	6.33	9	5	7.67	9	0.11	0.16	0.33	0.56	0.85	1.00	0.56	1.11	3.00	3.89	7.67	9.00						
T2	5	7	9	5	7	9	0.11	0.14	0.20	0.56	0.78	1.00	0.56	1.00	1.80	3.89	7.00	9.00						
T3	3	6.33	9	3	7	9	0.11	0.16	0.33	0.33	0.78	1.00	0.56	1.11	3.00	2.33	7.00	9.00						
T4	1	5	9	1	6.33	9	0.11	0.20	1.00	0.11	0.70	1.00	0.56	1.40	9.00	0.78	6.33	9.00						
T5	1	4.33	9	1	3.67	7	0.11	0.23	1.00	0.11	0.41	0.78	0.56	1.62	9.00	0.78	3.67	7.00						

6. Discussions and conclusions

The COVID-19 pandemic will prevail as an unforgettable cataclysm in global history and the damages caused to humanity are irreplaceable. Thus, humanity should consider this as an experience that prompts the need to observe, explore and envision the possibility of thriving humanity in context with this beautiful world. On the other hand, to impart immunity to humanity against such pandemics, we should learn the lessons from experience, develop strategies to effectively fight against it, and optimize those strategies. The answers for the previously raised concerns are as follows.

*What are the characteristics of the progress of pandemic and how to deal with the typical pandemic crisis effectively (from a management perspective)?*

There is no effective drug for either a treatment or a cure, nor a vaccine for the coronavirus (as of December 2020). Hence, strategic management of the pandemic is essential to mitigate the infection until there exist no traces of virus among the humans. The pandemic management will be different for the region where the outbreak emerges and in the regions to which the infection is transmitted. The disease-causing pathogen needs to be characterized, and preventive strategies and precautionary measures should be framed as early as possible and should be implemented with maximum efforts in the outbreak region. Failure to do so will cause the spread of the infection to other regions or countries and the complex situation of global pandemic results.

From the time when the global pandemic is declared, the pre-

Table 8

Obtained Fuzzy positive ideal solution (FPIS) and Fuzzy negative ideal solution (FNIS).

	Revitalization ability			Sustainability ability		
<b>Strength criteria</b>						
A+	0.56	1.40	9.00	3.89	8.33	9.00
A-	0.56	0.84	1.80	0.78	5.67	9.00
<b>Weakness criteria</b>						
A+	0.56	1.62	9.00	3.89	8.33	9.00
A-	0.56	0.91	3.00	0.78	5.67	9.00
<b>Opportunity criteria</b>						
A+	0.56	1.40	9.00	5.44	9.00	9.00
A-	0.56	0.91	3.00	0.78	4.33	9.00
<b>Threat criteria</b>						
A+	0.56	1.62	9.00	3.89	7.67	9.00
A-	0.56	1.00	1.80	0.78	3.67	7.00

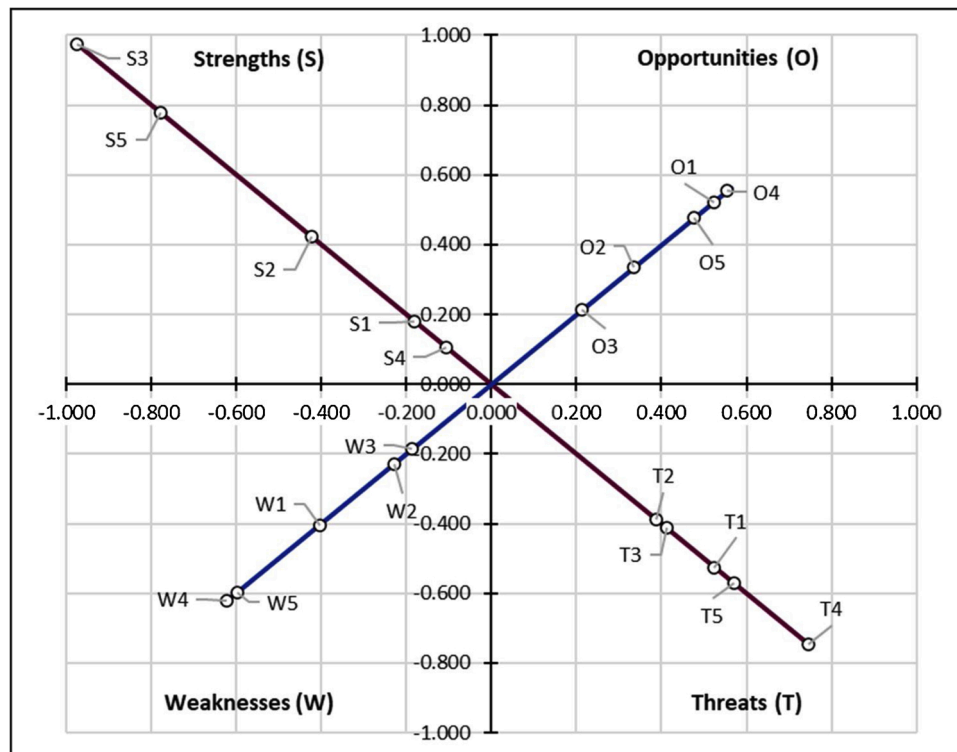
**Table 9**

Distance from FPIS and FNIS, Closeness coefficient and ranking corresponding to each SWOT factors (R - Revitalization ability; S - Sustainability ability).

SWOT factors	Distance from FPIS		Distance from FNIS		di+	di-	CCI	Rank
	R	S	R	S				
<b>Strengths</b>								
S1	4.169	1.183	0.000	1.183	5.352	1.183	0.181	4
S2	3.472	0.385	0.699	2.135	3.857	2.834	0.424	3
S3	0.170	0.000	4.160	2.366	0.170	6.525	0.975	1
S4	3.472	2.366	0.699	0.000	5.838	0.699	0.107	5
S5	0.000	1.463	4.169	0.977	1.463	5.147	0.779	2
<b>Weaknesses</b>								
W1	3.488	0.000	0.000	2.366	3.488	2.366	0.404	3
W2	4.172	1.463	0.695	0.977	5.635	1.672	0.229	4
W3	3.468	1.782	0.296	0.898	5.250	1.194	0.185	5
W4	0.219	2.135	3.469	0.385	2.355	3.854	0.621	1
W5	0.000	2.366	3.488	0.000	2.366	3.488	0.596	2
<b>Opportunities</b>								
O1	3.475	0.000	0.000	3.810	3.475	3.810	0.523	2
O2	3.468	1.463	0.111	2.366	4.931	2.477	0.334	4
O3	3.468	2.366	0.111	1.463	5.834	1.574	0.212	5
O4	0.095	3.311	3.469	0.770	3.406	4.239	0.554	1
O5	0.000	3.810	3.475	0.000	3.810	3.475	0.477	3
<b>Threats</b>								
T1	3.477	0.000	0.695	3.145	3.477	3.841	0.525	3
T2	4.172	0.385	0.000	2.875	4.557	2.875	0.387	5
T3	3.477	0.977	0.695	2.417	4.454	3.113	0.411	4
T4	0.124	1.954	4.163	1.925	2.079	6.088	0.745	1
T5	0.000	3.145	4.172	0.000	3.145	4.172	0.570	2

pandemic period begins and all countries should be keen on finding all the possible ways and events that might have involved people traveling from the region of the outbreak and monitor them. Hence, screening the fresh entries coming from the region of the outbreak should be given the

highest priority. Here there is a need for improvement to develop a cost-effective screening methodology. All the measures in the pre-pandemic period revolve around the central or federal government, such as framing plans, allotting budgets, imposing restrictions, supporting the



**Fig. 11.** Closeness coefficient plot for performed SWOT-Fuzzy TOPSIS analysis.

healthcare needs, and many others. Lockdown is the one and only effective method to contain the disease within a city. So, as the infection increases and progresses from one stage to another in terms of disease transmission, strenuous testing and tracing methods should be carried out hand-in-hand. Further, quarantining of asymptomatic patients and isolating and treating the symptomatic patients is pivotal. The relaxation of the lockdown must be avoided until there is a steady decrease in the reported new infected cases but, simultaneously, strategies must be framed to gain the support of the public for accepting the basic needs. The role of the public and government is highly influential and the better the cooperation between them, the more effective will be the implemented measures. There are numerous examples where the spreading of infection skyrocketed due to the lack of public cooperation and awareness. The role of healthcare is extremely pivotal as they face the risk of treating the infected persons and also, more importantly, scientists are constantly engaged in research activities to find a vaccine or at least an antiviral drug. Further, the government connects all the social bodies and, on every action or response that the government takes, the reaction in the pandemic will be reflected in the epidemiological curve followed by the impact on the economy. In addition, it is observed that the use of technology has helped a lot in managing the pandemic, and focusing on technology-based approaches can accelerate the revitalization.

In a worldwide pandemic situation, the pandemic will be unevenly distributed in terms of the time of occurrence and prevalence period across the different geographical areas of the world. One should understand the lag in experiencing the pandemic that each country would undergo from the pre-pandemic period to the post-pandemic period. This might give the necessary time for the preparedness required to tackle the pandemic at an early stage and it will also be useful in making decisions in the post-pandemic scenarios. In short, the pandemic demands the chain of closing the boundaries, centralized measures, screening, isolation, lockdown, and a loop of testing, tracing, treatment, quarantine, and finally a decentralized zoning strategy.

*What is the role of technologies in managing the pandemic and how it aids in minimizing the pandemic impacts in a technology-empowered society?*

Technology played a crucial role in mitigating the spread by supporting the healthcare sector and indirectly by supporting the people through various means to follow the quarantine. The role of various technologies in the pandemic were discussed under the categories of communication and connectivity, healthy and easy life, mobile technology and technology in mobility, digitalization, security and surveillance, Artificial Intelligence, Machine Learning, and Internet of Things. Also, an emphasis on their future role is provided under each of the above-mentioned categories. Further, the futuristic city is assumed with a certain focus on the progress of development and discussed with three elements where the technology can ultimately support humanity. The value of a kilowatt-hour no longer matters. Delivering that kilowatt-hour at the right time and to the right place is what matters and the energy sector will be revolutionizing this concept in the near-future. On the basis of this expectation, the energy model is built and it is clearly seen that the system possesses much more flexibility, reliability, efficiency and many other benefits for the city. Such an infrastructure can possibly address the unforeseen changes in power demand during the pandemic and even much greater advances can be seen in the energy sector, which all contribute to sustainable energy production and management. Secondly, the supply chain model aims at automating the raw material industry to sustain the flow of materials irrespective of the situation and taking a step forward to interconnect the retailers and the customers with a digital approach in the pandemic situation. By doing so, supply chains can function well in combination with the risk

management strategies and, the proposed customer-retailer interaction will minimize the gatherings in the shops. Finally, the presented tracking system merges the feature of alerting the individual to maintain social distancing and the important tracing feature. It works on a mixed decentralized and centralized approach where the sharing of data to the database will occur only in terms of unique anonymous IDs of the individuals. In a pandemic period, this will hasten the process of tracing and will support the protection of humanity. Hence, it is clear that the technology has a greater role in supporting humanity during pandemics from these futuristic scenarios and moreover, the pandemic induced impacts are minimized by creating a resilient city to adopt the changes.

*What are the post-pandemic strategies to minimize the pandemic impacts and to make the cities sustainable?*

The post-pandemic strategies to revitalize the society from the pandemic impacts are elucidated in Section 5. Among which the immediate measures are needed to reduce the increasing poverty rate, for expanding employment opportunities and to focus on sustainable developments. The effective management of the supply chain relies on strategic planning for choosing their suppliers and diversified interdependency characteristics. Investments in the post-pandemic period would drive the world either to become more sub-standard or more sustainable. As a whole, the digital approaches in the development progress should be entertained, developments that degrade the environment should be minimized, afforestation should be encouraged to lessen the occurrence of pandemics and epidemics, Sustainable Development Goals should be prioritized.

To step-up the analysis for directing the pandemic situation towards sustainable cities, a hybrid method of SWOT-Fuzzy TOPSIS methodology is incorporated. SWOT is utilized to picture the gravity of pandemic induced changes and Fuzzy TOPSIS is employed to identify the highest influencing factor in terms of its revitalization ability as well as sustainability ability under Strengths, Weaknesses, Opportunities, and Threats. The results indicates that the changes leading to reassessment of economic model with crisis management ability as prominent strength; lack of sound climate action measures and circular economy as penetrated weakness; healthy urban planning and reducing transportation time within cities should be prioritized as golden opportunity and management of pandemic induced wastes awaits as a major threat for making the cities sustainable.

We have seen the multifold factors on which effective pandemic management depends, but the nuance of technology provides the vital essence to expedite the process supporting each and every element involved in controlling the pandemic. To conclude, sharpening the weapon of technology by various means is indispensable to win the war against the pandemic while it is also a premium tool to direct the cities towards sustainable development. When the development is in the direction of sustainable manufacturing, sustainable agriculture and sustainable energy production and management in the post-pandemic world, the foundation for the sustainable cities is laid. The term sustainable cities when coined in context with the pandemic can be defined as the tendency of the city to provide maximum benefits for the betterment of humanity irrespective of the situation. Hence, by effectively managing the pandemic, minimum adverse impacts are obtained and the technology-empowered city shows much more flexibility and resiliency for any kind of situation, rewarding humanity with more significant benefits that substantiate the progress towards sustainability.

### 7. Limitations and future scope

This work presents a typical pandemic management approach in a society by analyzing the past and present experiences that humanity had been through the pandemics. With respect to all the pandemic experiences from the past century to the current coronavirus pandemic, the role of technologies in controlling the spread of disease is highly increased. Thus, this study emphasizes the extent of technological penetration in the current pandemic and also in mitigating the pandemic impacts in both present society and futuristic nexus society. The limitations for this analysis are illustrated as follows:

- This work signifies a skeletal approach (covering the important aspects of pandemic management) and therefore, the management strategies for various regions will vary depending upon the multi-dimensional factors associated with that region, which include political aspects, population nature, healthcare ability, and the like.
- The management of pandemic also depends on the characteristics of the pandemic, such as pathogen, disease transmission dynamics and many others, which is not emphasized to a greater extent in this work.
- The future is unpredictable with high precision. In context with it, the future pandemic may evolve with different scenarios and novel problems with the developed surroundings. In such a case, the response to the pandemic will vary and the management approach presented based on the current scenario might expire.
- The proposed three models such as energy model, supply chain model, and tracing system have been put forward with an assumption to incorporate the digital technologies at well-developed phase. Besides, uncertainty exists in describing the well-developed phase for a technology, and thus, the proposed models may suffer from proper technological interpretation in reality when defining the future.

The future scope of this work can be extended to include the forecasting models and multi-criteria decision analysis models in pandemic management inclusive of many factors such as temperature, climate, and population for a given pandemic nature. This in-depth analysis can

be performed on any flagship problems apart from pandemic (such as climate change) and can explore novel solutions and approaches through a sequence of research.

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### CRediT authorship contribution statement

**Rajvikram Madurai Elavarasan:** Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Validation, Writing - original draft. **Rishi Pugazhendhi:** Conceptualization, Formal analysis, Data curation, Methodology, Visualization, Writing - original draft. **G. M. Shafiullah:** Writing - review & editing. **Muhammad Irfan:** Formal analysis, Writing - review & editing. **Amjad Anvari-Moghaddam:** Writing - review & editing.

### Declaration of Competing Interest

The authors report no declarations of interest.

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### Appendix A

**Table A1**  
Linguistic ratings provided by three decision-makers for all SWOT factors.

SWOT factors	Decision Maker 1		Decision Maker 2		Decision Maker 3	
	Revitalization ability	Sustainability ability	Revitalization ability	Sustainability ability	Revitalization ability	Sustainability ability
<b>Strengths</b>						
S1	Very high	Very high	High	Average	Very high	High
S2	High	High	Average	High	Very high	Very high
S3	Very high	Very high	Low	Very high	High	High
S4	High	High	Average	Low	Very high	High
S5	High	High	Very low	Average	High	High
<b>Weaknesses</b>						
W1	Very high	Very high	Very high	Very high	Average	High
W2	High	High	High	High	High	Average
W3	Average	High	Average	Average	Average	Average
W4	High	Very high	Low	Low	High	High
W5	High	Very high	Very low	Very low	Average	High
<b>Opportunities</b>						
O1	Very high	Very high	Very high	Very high	Average	Very high
O2	High	High	High	High	Average	High
O3	High	Very high	Average	Average	High	Average
O4	Very high	High	Low	Low	Average	High
O5	High	High	Very low	Very low	High	Average
<b>Threats</b>						
T1	Average	High	Very high	Very high	Average	High
T2	High	High	High	High	High	High
T3	High	Very high	Average	Average	High	High
T4	High	Very high	Low	Low	Average	High
T5	Average	Average	Very low	Very low	High	Average



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