Smarter and Greener Cities After COVID-19: An Integrated Decision-Making Framework to Prioritize Investment Alternatives

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Locking down cities to curb the transmission of coronavirus brought the global economy to a grinding halt. Cities are like engines of growth; when they stop, so does the growth. Therefore, it becomes paramount to build cities that continue to function and do not collapse amidst any crisis. Since economic recovery is underway, this paper examines priority areas for investment to expedite recovery and build back stronger cities. These areas are evaluated based on their contribution to revitalizing public health, economic, social, energy, and environmental sectors. For the analysis, analytical network process (ANP) and fuzzy-VIKOR are applied. ANP obtains the relative importance of sectors and their respective critical factors after solving a complex relationship among them. The economic sector has the highest weight of 25.8% among the five sectors, while job creation has the highest weight of 10.3% among the fifteen factors. Fuzzy-VIKOR is used to evaluate different areas and it is found that renewable energy has a greater contribution to the sustainable recovery of major sectors and the long-term aim of building inclusive green and resilient cities. These insights shall contribute to the conversations already ongoing among city governments, urban planners, civil society organizations, and city dwellers seeking practical solutions to unprecedented challenges posed by the pandemic.

1. Introduction

COVID-19 demonstrated how the global economy ground to a halt when cities stopped working. Sweeping measures taken amid the crisis, such as mandated lockdowns, dawned upon us that cities were like engines of growth; when they stopped, so did the growth.[1] While the governments now pledging to spend more funds in reviving the economies, this paper argues that the economic stimulus must be directed to cities as they suffer the most. More precisely and as a lesson learned from the recent few years.[3] The International Monetary Fund indicated a 3.5% decrease in the global economy in 2020. The cumulative global economic loss is projected to be over $12 trillion by 2021. Job losses during 2020 were estimated to be 400 million full-time jobs – almost four times higher than during the 2009 global financial crisis.[4] These figures only highlight the economic losses that have occurred so far, whereas, the full economic repercussions of the crisis are yet to unravel.

The pandemic also laid bare fault lines of inequality, exclusion, and disadvantage in the urban centers, vividly exposing gaps in access to essential services among various social groups. In developing country cities, up to 70% of the population lacks access to basic services and infrastructure, depending instead on informal arrangements of water, sanitation, energy, and transportation.[5] Though the pandemic devastated urban residents altogether, its health and economic impacts on the urban poor, migrants, and low-income workers were more deleterious and disproportionate. For instance, the mortality rate of this population segment remained higher because of only affording health facilities with poor services. They lost their jobs at the highest rate due to being employed mostly in sectors that suspended their operations. Most of them were working in precarious hourly paid jobs, they were not able to access health insurance, social security, and emergency benefits that could cushion the loss of income and the impact of the cataclysmic crisis on their lives. Finally, their living patterns elevated their vulnerabilities as they live in small and crowded homes in densely populated areas where interventions to reduce the risk of contagion are more difficult.[6]
The vitality of energy access during the crisis is another major factor that the pandemic highlighted. First, we learned that maintaining health under pandemics relies on the ability of people to access independent and reliable energy. Health facilities require electricity to run medical equipment and enable health care delivery. For instance, the ventilator, which has come up as a symbol of intensive care response in the time of COVID-19, necessitates electricity. Second, the availability of electricity fosters essential communications under extended lockdowns and quarantine measures imposed by the governments. Finally, electricity access is paramount in mitigating the impacts of COVID-19 and fueling economic recovery. Yet, in cities of the developing world, 132 million people have no access to electricity; even those with access have to face 8–10 hours of a power outage.[7] Cities, that were already struggling to provide reliable, affordable, and clean energy to their residents, are now faced with a greater challenge of ensuring sustainable power supply to everyone as the economic impacts of COVID-19 have debilitating more than 25 million people in Asia and Africa to afford electricity.

Amid all this upheaval, the positive impacts of COVID-19 were apparent on the environment. In urban areas, air pollution reportedly plummeted by up to 45% during lockdowns, especially due to a drop in transportation, energy generation, and industrial activities accompanied by a reduction in other sources of pollution. According to the World Health Organization, dirty air cuts short seven million lives a year. Though the pandemic-driven decline in air pollution was short-lived, it paints a picture. The clearing of the air – when businesses were shuttered and billions of people were home-confined – revealed benefits that could be reaped from a sustainable and lasting reduction in air pollution. Healthier air for the longer term cannot be achieved by restricting people at home at a drastic economic cost, but by letting go of the status quo that was in place before this crisis and by implementing new measures that are sustainable and environmentally friendly.

The facts presented above emphasize the urgency and significance of a sustainable recovery; and therefore, scholars have committed their efforts to evaluating routes for a sustainable recovery from the pandemic. Numerous researchers have offered various paths. For instance, González-Sánchez et al.[8] proposed attaining sustainable recovery through ensuring sustainable mobility and gender equality in urban areas. They carried out a comprehensive evaluation of urban mobility in the context of COVID-19 from the standpoints of sustainability and gender equity, identifying a variety of effective strategies to deal with the post-pandemic urban mobility scenario. Acuto et al.[2] urged for a better knowledge of “how COVID-19 develops in urban environments” in order to rebuild in a more sustainable manner. They proposed doing so by addressing the urban disparities that underlay the crisis, as well as appreciating the basic inclusive development potential that exists here if we bring urban knowledge, and cities, nearer to the core of the global response. Shah et al.[9] emphasized the importance of sustainable energy in driving green economic recovery. They contended that if conventional energy policies continue, carbon emissions would exceed pre-COVID-19 levels, resulting in further calamities in the future. Furthermore, the authors offered pathways for sustainable waste management and waste to energy.

Cook and Taylor assert that nature serves as a foundation for economies and society on numerous levels.[10] The authors contend that it is now more important than ever to make an intelligent investment in nature-based solutions. According to them, nature-based solutions must play a significant role in COVID-19 economic recovery plans because of the triple dividend, which entails economic gains, averted losses, and social and environmental advantages. Additionally, their arguments suggest that developing countries, which significantly rely on nature for their livelihoods and sources of income, should find nature-based solutions to economic stimulation and recovery to be particularly appealing. Lahcen et al.[11] estimate the potential for public expenditures in green construction initiatives to support economic recovery while also benefiting the environment by reducing energy usage and associated greenhouse gas emissions. Their findings suggest that the COVID-19 outbreak generates considerable economic damage, but that the reduction in emissions has been inadequate. However, the authors believe that properly thought-out public policies can balance this tendency, leading to both economic growth and a significantly large reduction in emissions.

With the increasing number of studies on the post-COVID-19 recovery, numerous overlapping policy schemas are developing, making it difficult to establish which areas should be considered for investment. No research in the literature has attempted to give a full evaluation of these areas and prioritize them in order to make decision-making easier for decision-makers. To address this issue, this study presents a decision-making framework for evaluating and prioritizing several areas for sustainable recovery. Prior to prioritization, a detailed review of the literature shall be conducted to identify the multiple driving factors for a sustainable recovery in each sector. The alternative areas shall then be prioritized in relation to the identified factors. The proposed approach shall be applied to the case study of Pakistan, a developing country in South Asia. The primary contribution of this study is the simplification of the difficult decision-making process of “where to invest for attaining a quick, resilient, and sustainable rehabilitation of cities?” The findings of the study shall hopefully help the current discussions among city governments, urban planners, civil society groups, and city inhabitants seeking practical answers to unprecedented challenges.

2. Proposed Decision-Making Framework

COVID-19 has altered the shape of cities and changed urban life worldwide. The crisis is another once-in-a-century test of global resilience, and cities once again remained the theatres of the crisis. The UN Secretary-General urges for a better appreciation of how the pandemic unfolds in an urban world to rebuild more sustainably. Likewise, the scientific community calls for an expedited recovery in almost every sphere of city life. In turn, the number of studies on the topic is growing, and different generic areas for stimulating recovery are being suggested concerning not only public health but also green economic recovery, environmental sustainability, energy security, and social equality. Such areas can be suitable for some countries and not for others. Therefore, it becomes pertinent to
analyze these areas beforehand and invest in those which offer maximum benefits and are feasible in the context of any particular country or region.

To find out the relative importance of policies, a framework is proposed in this study. The proposed framework comprises five steps as shown in Figure 1. The initial step in the framework sorts out driving factors that are vital for the recovery and restoration of each sector. In the later step, priority areas are extracted from the literature survey. Identified factors and priority areas for investment are searched from scientific literature, magazines’ articles, and news blogs using major search engines such as Google, Google Scholar, ScienceDirect, and Microsoft Academic.

In the third step, an experts’ panel is finalized. The experts shall be consulted for their feedback, which shall be processed through different techniques to obtain the final results.

The fourth step finds the relative importance of sectors to see how sectors must be given priority in recovery stimulus to not only obtain short-term recovery but a sustained resilience. Similarly, the relative importance of each factor under the respective sector shall be found. To compute the relative importance of sectors and their respective factors, the most efficient multi-criteria decision making (MCDM) technique, analytical network process (ANP), shall be used. The ANP takes sectors as criteria and factors as sub-criteria of respective criteria. Finally, it computes relative weights after establishing all the possible interdependent relationships among criteria and sub-criteria.

The final step prioritizes selected policy agendas that shall simplify the complex decision-making of “where to invest the recovery stimulus for obtaining maximum short term as well as long term benefits.” For prioritization, another widely recognized method of MCDM, VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), shall be applied. Since we integrate ANP and fuzzy VIKOR, weights of criteria and sub-criteria obtained using ANP shall be used in fuzzy VIKOR analysis. The fuzzy set theory proposed by Zadeh is introduced to minimize fuzziness in experts’ feedback.

2.1. Identification of Driving Factors

The literature yielded a total of twenty factors for recovery in five primary sectors, which are briefly described in this section. The list of identified factors along with key references is given in Table 1.

2.1.1. Economic

Jobs Creation: The pandemic significantly disrupted labor markets as millions of people lost their jobs globally. As nations emerge from the pandemic, a focus on jobs creation shall be a keystone while strategizing economic recovery and enhancing workforce confidence.

Income Generation: The COVID-19-related restrictions have created adversities for daily-wage earners. While many countries have already launched initial recovery measures, a certain

Table 1. Driving factors for recovery in five major sectors.

| Sector         | Driving factors                          | Code | Key references       |
|----------------|------------------------------------------|------|----------------------|
| Economic       | Jobs creation                            | Ec-1 | [12–14]              |
|                | Income generation                         | Ec-2 | [15–17]              |
|                | Economic growth                           | Ec-3 | [9,14,18–20]         |
| Social         | Increase community resilience             | Sc-1 | [21–23]              |
|                | Reduce inequality                         | Sc-2 | [24–26]              |
|                | Poverty alleviation                       | Sc-3 | [24,27]              |
| Environmental  | Reduce carbon emission                    | Ev-1 | [28–31]              |
|                | Reduce air pollution                      | Ev-2 | [28,29,32,33]        |
|                | Protect and conserve biodiversity          | Ev-3 | [34–36]              |
| Public health  | Improve water quality                     | Ph-1 | [37–39]              |
|                | Sustainable waste management              | Ph-2 | [9,40–42]            |
|                | Safe sanitation                           | Ph-3 | [14,43,44]           |
| Energy         | Increase access to reliable and clean energy | Eg-1 | [9,45–47]           |
|                | Reduce fossil fuel energy consumption     | Eg-2 | [9,29,45,46,48]      |
|                | Increase energy affordability             | Eg-3 | [9,45,46,49]         |
population segment, such as the income-earning poor in the informal economy is disproportionately influenced by the pandemic and needs extra support. The specific action is required to help such disadvantaged groups who shall bear the maximum burnt of the crises today in days to come.

Economic Growth: The pandemic evolves from a public health crisis to become a major economic crisis. The damage that the pandemic has caused to the economic activities is already evident representing the worst recession in nearly a century. However, the full extent of the pandemic is still unfolding. After the pandemic is under control, it is critical to cushion the pandemic's economic consequences and implement reforms to support economic growth.

2.1.2. Social

Increase Community Resilience: Building community resilience is an effective way for risk governance. It means that the quality of life is improved in a way that maintains health, social, economic, and environmental processes on which life depends. In other words, “community resilience serves as the capability of a system to endure through disasters via adaptation and occasional transformation.” Thus, building resilience is critically important for a community to sustain itself through any change or disaster.

Reduce Inequality: The COVID-19 has shown us how the status quo led to disproportionate vulnerability to the pandemic, as the marginalized segment of the population had to face the utmost health, economic, and social burden. The pandemic also showed how strongly connected/interdependent we are in a society that if one segment is unable to cope, it leads the whole society to fail. Therefore, this pandemic should be taken as an opportunity to devise policies that channel resources to disadvantaged communities and reduce inequality.

Poverty Alleviation: Poverty remains the main barrier to ceasing COVID-19 spread. Developing countries especially Southeast Asian and Sub-Saharan African countries cannot implement SOPs to contain COVID-19 since a significant portion of the population in these countries lives in abject poverty. Large numbers of urban citizens in these countries live in densely packed, precarious, and underserved slums, and are involved in high levels of informal employment. Adhering to social distancing measures is not possible for such inhabitants especially when they effort to avoid starvation. Therefore, enhancing coping ability through poverty alleviation should be a priority consideration.

2.1.3. Environmental

Reduce Carbon Emission: Numerous recent studies efficaciously establish the connection between environmental degradation and the pandemic outbreak. They warn us to take immediate actions against any further degradation and scale up our efforts to protect it or be ready for more panemics of an even bigger scale and for the biggest threat to the world that is climate change. So far, carbon emission is the chief culprit triggering environmental destruction. And for that, the world economies decided in the Paris Agreement to limit carbon emission to less than 1.5 °C. Therefore, recovery stimulus must ensure no deviation from the Paris Agreement of decarbonization.

Reduce Air Pollution: Across the world, air pollution kills approximately 4.2 million people annually. Low- and middle-income countries bear the most brunt of this as nearly 91% of deaths occur in these countries, particularly in Southeast Asia. Scientists wondered if the rate of COVID-19 deaths in severe air pollution places was higher. They found a statistically strong link between high air pollution levels and COVID-19 deaths and COVID-19 transmission. Analysis conducted in early 2020 in numerous countries exhibited an association between air pollution and COVID-19 mortality. Given the clear linkage between the impacts of COVID-19 and air quality, reduction of air pollution must be central in devising any recovery plan.

Protect and Conserve Biodiversity: The emanation of COVID-19 from the wild confirms that our health is intimately connected to our way of dealing with nature. Our continued encroachment on nature and depletion of vital habitats causes the extinction of several species. If we do not build back better from here, continue to overexploit wildlife, and annihilate biodiversity, we shall be in danger.

2.1.4. Public Health

Improve Water Quality: The reduction in economic activities due to the pandemic led to a significant improvement in water quality. Many regions and countries reported a reduced concentration of water pollutants. However, if economic activities resume similarly as, during the pre-COVID-19 era, improved water quality shall become a temporary phenomenon and water pollution shall mount eventually.

Sustainable Waste Management: Sustainable waste management after the pandemic has become an increasingly significant challenge that has be to deal with in the recovery phase. The use of disposable personal protective equipment has increased medical waste. After governments mandated masks, the use of disposable masks has skyrocketed. Demand for single-use plastic such as for groceries, health care, food delivery, and e-commerce packaging has also increased. Recycling capacity has reduced and the market price for recycled plastics has collapsed.

Safe Sanitation: Safely managed sanitation and hygiene are integral for shielding human health during outbreaks of infectious diseases, including COVID-19. One of the core areas for enhancing public health infrastructure, particularly in settings with limited resources, is to invest in a safe sanitation system. Consistent safe sanitation practices in communities, homes, marketplaces, healthcare facilities, and schools serve as an impediment to COVID-19 transmission. Likewise, a safe sanitation system is essential during the post-pandemic recovery phase to minimize secondary impacts on community wellbeing and livelihoods.

2.1.5. Energy

Increase Access to Reliable and Clean Energy: The pandemic has firmly underlined the central role that reliable energy
access can play in safeguarding health and wellbeing, and in aiding key public services, people's livelihoods, supply chains, and countries' economies. Similarly, access to clean energy is equally important as it offers solutions that are in line with climate targets and buffers the effects of the pandemic on livelihoods and economies.

Reduce Fossil Fuel Energy Consumption: The adverse environmental repercussions of fossil fuel energy consumption are well documented. In the recent pandemic, the world also experienced how fragile the fossil energy supply could be amidst any crisis. A historic plunge in oil prices escalated uncertainty among businesses and triggered price volatility. Therefore, a substantial reduction in its consumption in the future is encouraged.

Increase Energy Affordability: Increasing energy affordability is one of the underlying elements of the goal of ensuring universal access to energy. The low-income population who cannot afford energy access engages in hazardous coping strategies that lead to serious public health issues. This happens on normal days; however, the pandemic exacerbated this problem. In a post-pandemic online era (online classes, online, business, work from home, etc.), this segment of the population was mostly cut off from the mainstream. Thus, the need to initiate interventions for making energy affordable is not only imperative but urgent as well.

2.2. Pathways for Sustainable Recovery

Six investment areas have been identified to facilitate sustainable recovery. These areas offer substantial dividends for major sectors, can easily be implemented, entice sustained private-sector investment beyond the preliminary public spending, and present other numerous opportunities for building green, resilient, and inclusive economic transformation that is vital for the post-pandemic world. The list of priority areas along with their major outcomes and literature base is given in Table 2.

2.3. Methods

This study employs ANP and fuzzy VIKOR. A brief introduction of these methods and the steps applied are elaborated in the following two sub-sections.

Table 2. Alternative areas for sustainable urban recovery.

| S. No. | Areas for investment          | Description                                                                 | Key references |
|-------|------------------------------|-----------------------------------------------------------------------------|----------------|
| 1     | Waste and resources          | Upgrading the waste and resources sector shall lead to sustainable waste management and develop a circular economy for resource-smart clean cities. | [41,44,50–53] |
| 2     | Renewable energy             | Investment in renewable energy shall enable access to clean and reliable energy and build low-carbon cities. | [9,14,58,45–47,50,34–57] |
| 3     | Active mobility              | Active transport shall foster cycling and pedestrian schemes resulting in healthy and active citizens. | [59–63] |
| 4     | Clean transportation         | Clean mobility shall promote clean transport for cities.                    | [14,56,64–66] |
| 5     | Green construction and retrofits | Investment in green construction and retrofit shall enable people to live a healthy life through developing "low-carbon built environments." | [12,63,67–71] |
| 6     | Nature-based solutions       | Nature-based solutions shall deliver green spaces to benefit citizens as well as cities. | [10,63,65,72–77] |

2.3.1. ANP

ANP in this study has been used to compute the weights of criteria and sub-criteria. Unlike the analytical hierarchy process (AHP), ANP first develops interdependence relationships among criteria and sub-criteria and then computes their respective weights. The development of a network which instead of a hierarchy among elements gives an edge to ANP to solving more complex decision-making problems. The ANP structures decision problem in a network which does not assume that the higher-level elements are independent of lower-level elements. According to[78] three steps are involved in implementing the ANP model. Firstly, pairwise matrices are constructed to evaluate the interactions among the elements and develop a problem framework. For constructing pairwise matrices, the subjective evaluations by the experts were collected using Saaty’s proposed judgmental scale,[79] that is given in Table 3.

Later, a supermatrix is derived based on the priority vectors. A supermatrix is a matrix that shows interdependence among the elements and is drawn from limiting powers of priorities. The matrix calculates the overall priorities and therefore obtains the cumulative influence of every single element on other elements it interacts with.[80] The formation of supermatrix at element/sub-criteria level – used in this study – follows as:

\[
\mathbf{W} = \begin{bmatrix}
C_1 & C_2 & \cdots & C_m \\
W_{11} & W_{12} & \cdots & W_{1m} \\
W_{21} & W_{22} & \cdots & W_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
W_{n1} & W_{n2} & \cdots & W_{nm} \\
\end{bmatrix}
\]

\(W\) here represents a partitioned matrix whose entries are composed of priority vectors obtained from solving the pairwise comparisons. Because the \(W\) matrix is stochastic, its limiting priorities rely on the reducibility of that matrix. In case if the matrix is primitive and irreducible, then the limiting value shall
be obtained by increasing the $W$ matrix to powers as shown in Equation 2 to obtain global priority vectors.\(^{[80]}\)

$$\lim_{k \to \infty} W^k$$

(2)

finally, the power of the supermatrix is increased until convergence occurs. For instance, the power of supermatrix is increased until it becomes $W^{2k+1}$, where $k$ is a random large number used to capture interactions and obtain a consistent outcome.

### 2.3.2. Fuzzy VIKOR

Fuzzy VIKOR has been applied to prioritize areas alternatives based on the relative importance of criteria and sub-criteria computed using ANP. The VIKOR method was specifically designed and proposed to solve discrete decision-making problems having complex and conflicting criteria.\(^{[81]}\) Compared to other MCDM methods, VIKOR offers maximum utility to decision-makers for the prioritization of alternatives.\(^{[82]}\) To increase the efficacy of the VIKOR method in dealing with the uncertain and ambiguous judgment of experts, we amalgamated the method with the fuzzy set theory. Thus, the fuzzy VIKOR in this study is applied in the following steps:

Initially, a fuzzy performance comparison matrix is constructed to assess alternatives for criteria and sub-criteria. The fuzzy linguistic scale with TFNs shown in Table 1 is used to draw comparison matrices. Let $\hat{D}$ denotes the comparison matrix that can be mathematically expressed as

$$\hat{D} = \begin{bmatrix}
    c_{11} & c_{12} & \ldots & c_{1n} \\
    a_{11} & \tilde{f}_{11} & \tilde{f}_{12} & \ldots & \tilde{f}_{1n} \\
    a_{21} & \tilde{f}_{21} & \tilde{f}_{22} & \ldots & \tilde{f}_{2n} \\
    \vdots & \vdots & \vdots & \ddots & \vdots \\
    a_{m1} & \tilde{f}_{m1} & \tilde{f}_{m2} & \ldots & \tilde{f}_{mn}
\end{bmatrix}$$

(3)

where, $A_{lk}$ represents alternatives, i.e., alternatives $k (k = 1, 2, 3, \ldots, m)$; $C_{rn}$ shows criteria $j (j = 1, 2, 3, \ldots, n)$; and $\tilde{f}_{lj}$ is a fuzzy comparison of performance having limits $l_{ij}, m_{ij},$ and $u_{ij}$.

Later, we shall obtain the ideal points of criteria $[\tilde{f}^* = (l^*, m^*, u^*)]$ and nadir points of criteria $[\tilde{f}_n = (l_n^*, m_n^*, u_n^*)]$ using the following respective benefit and cost functions:

$$\tilde{f}_j^* = \max_k \tilde{f}_{kj}; \tilde{f}_j^* = \min_k \tilde{f}_{kj} (j \in J^*)$$

(4)

$$\tilde{f}_j^* = \min_k \tilde{f}_{kj}; \tilde{f}_j^* = \max_k \tilde{f}_{kj} (j \in J^*)$$

(5)

Now, we shall find the normalized fuzzy difference. Let $\bar{d}_{kj}$ denotes the normalized fuzzy difference which can be computed as

$$\bar{d}_{kj} = \frac{\tilde{f}_j^* - \tilde{f}_{kj}}{u_{kj} - l_{kj}} j \in J^*; \bar{d}_{kj} = \frac{\tilde{f}_j^* - \tilde{f}_{kj}}{u_{kj} - l_{kj}} j \in J^*$$

(6)

After that, the values of the maximum group utility $\bar{S}_{kj} = (S^1, S^2, S^3)$ and minimum individual regret $\bar{R}_{kj} = (R^1, R^2, R^3)$ of normalized fuzzy difference shall be computed respectively as:

$$\bar{S}_{kj} = \sum_{j=1}^n (w_j \odot \bar{d}_{kj})$$

(7)

$$\bar{R}_{kj} = \max (w_j \odot \bar{d}_{kj})$$

(8)

The overall distance from maximum group utility (also known as the ideal solution) is obtained as

$$\bar{Q} = \sqrt{\bar{S}_k \ominus \bar{S}_k} \ominus (1 - v) \tilde{S} \ominus \bar{R} \ominus \bar{R}$$

(9)

where, $\tilde{S} = \min \bar{S}_k, S^* = \max \bar{S}_k$; $\bar{R} = \min \bar{R}_k, R^* = \max \bar{R}_k$; $v$ is the weight of maximum group utility; and $(1 - v)$ is the weight of minimum individual regret.

The obtained fuzzy values of $\tilde{S}_k$, $\bar{R}_k$, and $\bar{Q}_k$ shall be defuzzified using the “2nd weighted mean” method (more detail can be found in\(^{[83]}\)) given in the following equation:

$$\text{Crisp} (\tilde{N}) = \frac{(l + 2m + u)}{4}$$

(10)

After defuzzification, alternatives are ranked by sorting crisp ($S$), crisp ($R$), and crisp ($Q$) in ascending order. The results are three ranking lists such as $\{A\}_S$, $\{A\}_R$, and $\{A\}_Q$.

Here, alternative $A^{(i)}$ is proposed as a compromised solution which is ranked best by $Q\{A\}_Q$ in case if subsequent two conditions are satisfied:

**Condition 1**: “Acceptable Advantage”: $Adv \geq DQ$ where $Adv = [Q(A^{(i)}) - Q(A^{(th)})]/[Q(A^{(th)}) - Q(A^{(th)})]$ is the rate of advance of alternative $A^{(i)}$ ranked first, alternative $A^{(i)}$ ranked second in $Q\{A\}_Q$, while $DQ = 1/(m - 1)$ is the threshold, and $n$ is the number of feasible alternatives.

**Condition 2**: “Acceptable Stability in the decision-making”:
The alternative $A^{(i)}$ must also be ranked best by $S$ and/or $R$.

If any of the above conditions are not satisfied then we shall obtain a compromise solution as:

1. Alternative $A^{(i)}$ and Alternative $A^{(j)}$ if the only Condition 2 is not satisfied, or

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Table 3. ANP Judgmental Scale.

| Importance | Description |
|------------|-------------|
| 1          | Both activities have equal importance |
| 2          | One activity has slightly more importance over the other. |
| 3          | One activity is moderately important than the other. |
| 4          | One activity has slightly more than moderate importance. |
| 5          | One activity is strongly important than the other. |
| 6          | One activity has slightly more than strong importance. |
| 7          | One activity has very strong importance over the other. |
| 8          | One activity is slightly more than very strong importance. |
| 9          | One activity has extreme importance over the other. |

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2. Alternatives $A^{(1)}$, $A^{(2)}$,..., $A^{(M)}$ in case of Condition 1 is not satisfied; $A^{(M)}$ is obtained by the relation $|Q(A^{(M)}) - Q(A^{(1)})| \leq DQ$ for maximum $M$ (the positions of these alternatives are in closeness).

3. Case study

The proposed framework is applied to the case study of Pakistan, a developing country in South Asia – one of the regions most affected by the pandemic. Like other countries, cities in Pakistan are the hub of economic activities. Due to the lack of facilities in rural areas of the country, the number of people moving from rural to urban areas, in pursuit of economic opportunities, better health, and quality education, is increasing.[83] The rate of urbanization has tremendously upsurged since the last decade thrusting cities into catastrophic states by exacerbating problems such as overcrowding, social inequality, environmental degradation, congested housings, increasing slums, deteriorating water and sanitation, poor public health, etcetera.[84,85] When the pandemic hit, such urban problems added fuel to the fire resulting in a rampant spread of corona disease across the country.

The pandemic exposed the fragility of cities which buckled under the pressure of the crisis without putting a deterrence or showing any strength of resilience. Halting economic activities in cities led to a net job loss of 0.7 million in 2020 and a contraction in gross domestic product (GDP) growth to a negative 1.5%. In the same year, nearly 2.5 million people in the country were pushed into abject poverty.[6] At the times when the pandemic has devastated all the major urban sectors in the country, there lies a silver lining opportunity to give up on old policies and act on new ones that can help build back better, resilient, and sustainable cities.[83]

The prioritization of investment areas is based on the opinion of local experts – such prioritization can be more effective since the local experts have a deeper grasp and knowledge of the country, allowing them to offer insightful judgments on what would stimulate sustainable recovery. Because the performance and application of the findings are primarily reliant on the judgments of the experts, it must be ensured that the experts are competent. Furthermore, the opinions of experts from different institutions may differ significantly due to differing viewpoints.[86] Consequently, equitable involvement from all areas is required to avoid any specific institution’s domination. Taking these essential factors into consideration, a committee of twenty experts from diverse backgrounds, including academia, research consultancies, government, and civil society organizations, was formed. Table S-1 in the Supporting Information lists the essential features of the experts.

4. Results

The results of this study are presented in three parts. In the first part, all the possible interdependence relationships among criteria and sub-criteria are established. In the second part, ANP is applied to obtain the relative weights of criteria and sub-criteria. In the final part, fuzzy VIKOR is used to prioritize alternatives concerning the relative weights of criteria and sub-criteria obtained using ANP.

4.1. Determine the Interdependence Relationship Among the Criteria and Sub-criteria

Initially, the interdependence among criteria and sub-criteria is determined to develop inner and outer dependence among clusters. The relationship developed for the current study is portrayed in Figure 2, which comprises two stages. In the first stage, an interdependence can be seen between criteria and sub-criteria. In the second stage, inner and outer dependence among sub-criteria can be found. Firstly, the sub-criteria nodes within each criteria cluster are found to have inner dependence. For instance, under Economic criteria, Ec-3 affects Ec-1 and Ec-2. It can also be seen that three (Economic, Energy, and Public Health) out of five criteria have outer dependence.

For instance, Ec-3 node in the Economic cluster influences Sc-1, Sc-2, and Sc-3; Eg-1 in Energy cluster has an external effect on Ec-1, Ec-2, Ec-3, Ev-1, Ev-2, Ev3, Sc-1, Sc-2, and Sc-3; whereas, Ph-2 in Public Health has an outer effect on Ev-2 and Ev-3. Sub-criteria nodes under Social and Environmental clusters do not have any external effect.

4.2. Compute Criteria and Sub-Criteria Weights Using ANP

After establishing an interdependence relationship among criteria and sub-criteria, their priority weights were computed using steps elaborated in sub-Section 2.3.1. The initial step in calculating priority weight was to construct pairwise comparison matrices using experts’ judgment. Before entering the feedback data into the Super Decision software, the geometric mean method was employed to reach a common group decision from the feedback of twenty experts. The geometric mean
method has been widely applied in ANP to minimize the influence of extreme values given by decision-makers while making a group decision. Results of priority weights computed for criteria and sub-criteria are shown in Figure 3. The consistency index of all pairwise matrices was checked accordingly to ensure that the comparisons drawn were consistent. Later, weighted supermatrix and limit supermatrix were formed that are respectively given in the Supporting Information Tables S-2, and S-3. After the final calculations, it was found that the experts preferred the economic criterion as the most important and, therefore, this criterion received the highest weightage of 0.258. Social criterion obtained the second-highest weightage of 0.243. Then comes the public health criterion, which got 0.218 weightage. Environmental and energy criteria received the second lowest and lowest weights of 0.142, and 0.139, respectively. Among economic sub-criteria, the Ec-1 criterion achieved the highest weight of 0.401 followed respectively by Ec-2 (0.375), and Ec-3 (0.224). Sc-1 obtained the highest weight of 0.387 under the social criterion, Sc-3 ranked second with 0.344 weight, and Sc-2 received the lowest weight of 0.270. Under environmental criterion, Ev-2 topped with a priority weightage of 0.413, Ev-1 got 0.317 and therefore came second in the row, and Ev-3 achieved the lowest weight of 0.270. Among public health criteria, Ph-1 got the highest weight of 0.467, followed by Ph-2, and Ph-3, which respectively came second and third having priority weights of 0.326, and 0.207. Finally, under the energy criteria, Eg-3 ranked first by achieving 0.521 weight, Eg-1 got second place with 0.321 weight, whereas, Eg-2 stayed at the bottom by getting 0.158 weight.

Finally, limit weights of sub-criteria were obtained, which are shown in Figure 4. Limit weights are the final weights that shall be used in fuzzy VIKOR to prioritize area alternatives. The sum of all the limit weights of sub-criteria equals 1. Among the total number of fifteen sub-criteria, Ec-1 (Jobs Creation) sub-criterion topped the list by obtaining the highest weight of 0.103, which translates to Ec-1's greater importance over other sub-criteria. Ph-1 (Improve Water Quality) achieved 0.012 weight, which is nearest to that of Ec-1. On third in the ranking is Ec-2 (Income Generation) which achieved 0.094 and 0.084 weights. Eg-3 (Increase Energy Affordability) came next with 0.072 weight. Ph-2 (Sustainable Waste Management) received a slightly lower weight (0.071) than Eg-3 and thus was next in the row. Sc-2 (Reduce Inequality), the last social sub-criterion remaining, received the eighth position with 0.065 weight. Ev-2 (Reduce Air Pollution) ranked ninth with 0.059 weight; it remained the highest limit weight obtaining sub-criterion among environmental sub-criteria. The last remaining economic sub-criterion, Ec-3 (Economic Growth), obtained 0.058 and positioned tenth in the ranking. Eg-1 (Increase access to reliable and clean energy), Ev-1 (Reduce Carbon Emission), and Ph-3 (Safe Sanitation) received equal weights of 0.045 each. Ev-3 (Protect and Conserve Biodiversity) got second the last position with 0.038, and finally, Eg-2 (Reduce Fossil Fuel Energy Consumption) was ranked lowest by obtaining the least weight of 0.022.

4.3. Prioritize Alternatives Using Fuzzy VIKOR

Following the evaluation of criteria and sub-criteria, and computation of their relative weights, fuzzy VIKOR was employed.
to prioritize areas alternatives. Before asking experts to score alternatives, they were briefed about the essence of the analysis which is to measure the contribution of alternatives towards sub-criteria and then rank alternatives according to that contribution. Experts scored each alternative concerning each sub-criterion. After compiling each expert’s opinion, individual findings were sent back to experts separately for their final confirmation. Only a few experts made changes to their initial feedback while most of them endorsed their previous judgments.

To process the experts’ feedback, fuzzy VIKOR’s steps given in Section 2.3.2 were followed. Initially, linguistic values were converted into fuzzy TFNs. Then, the integrated matrix was drawn that is given in the Supporting Information Table S-4. Ideal and nadir values were computed using the benefit function given in Equation 4 as all the sub-criteria belonged to the benefit-type category. Subsequently, the fuzzy difference was obtained using the benefit function of Equation 6. Before computing maximum group utility and minimum individual regret, a fuzzy difference matrix was integrated with limit weights of sub-criteria that were obtained using ANP. Values of maximum group utility \( S_k \) and minimum individual regret \( R_k \) were used to compute distances of the alternatives from the ideal solution \( Q_k \). All these values were obtained in TFNs which were then converted into crisp numbers. Finally, alternatives were ranked using crisp values as shown in Table 4.

5. Discussion

As the lockdown in many countries eases or is totally removed, recovering the key industries has become the primary goal of nations. Cities, being the driving force behind every country’s growth, are where the recovery process begins. Furthermore, cities were in the vanguard of the pandemic and bore the brunt of the consequences. However, before beginning the recovery process, the lessons acquired from the pandemic must be preserved and followed in their entirety. It was evident how cities fell miserably as the pandemic continued to rampage. “Should we continue along the same traditional pathways that brought cities to the verge of extinction, or should we change our ways and adopt policies that will make cities more sustainable and crisis-resistant?” The world’s leaders and scientific community concur on the latter. They insist on a complete transition from conventional to sustainable paths for reaching the UN Sustainable Development Goals—goals aimed at making the planet more resilient and livable.

The emphasis on sustainable recovery for building resilient cities has upsurged the number of studies on the topic. A variety of investment areas have been suggested in the literature for achieving a sustainable recovery as well as long-term sustainable development. Six most widely suggested priority areas are selected in this study for further analysis. These areas include nature-based solutions, clean mobility, renewable energy, active transport, green construction and retrofits, and, waste and resources. It is understood that the priority of investing in these areas varies according to different countries. For instance, the purpose of intervention is to contribute to the factors driving sustainable recovery in major and hardest-hit sectors such as economic, public health, social, environmental, and energy. Thus, prioritizing investment areas concerning different factors becomes obligatory before proceeding with the economic stimulus. For this purpose, this study proposes a decision-making framework that shall evaluate different intervention areas by engaging and getting feedback from local experts.

Before prioritizing, the study first obtained the relative importance of sectors. In other words, which sector shall be more important in making cities sustainable and resilient. Later on, the relative importance of factors identified for each sector was found. The relative importance of sectors and their respective factors were computed using the ANP method, which established complex networking among sectors and factors before computing their weights. These weights were integrated into fuzzy VIKOR so that the alternatives can be evaluated for all the factors and subsequently prioritized.
Table 4. Ranking of alternatives using fuzzy VIKOR.

| Alternatives                           | Crisp ($S_i$) | Ranking | Crisp ($R_i$) | Ranking | Crisp ($Q_i$) | Ranking |
|----------------------------------------|---------------|---------|---------------|---------|---------------|---------|
| Nature-based solutions                  | 0.2479        | 4       | 0.0506        | 4       | 0.1411        | 4       |
| Clean mobility                          | 0.2239        | 3       | 0.0505        | 3       | 0.1320        | 3       |
| Renewable energy                        | 0.0744        | 1       | 0.0344        | 1       | 0.0000        | 1       |
| Active transport                        | 0.3447        | 6       | 0.0591        | 5       | 0.2170        | 6       |
| Green construction and retrofits        | 0.2737        | 5       | 0.0632        | 6       | 0.2106        | 5       |
| Waste and resources                     | 0.1430        | 2       | 0.0434        | 2       | 0.0683        | 2       |

The results indicated the economic sector to be the most important followed respectively by the social, public health, environmental, and energy sector. Ec-1 was recognized as the most vital factor for recovery in the economic sector, Sc-1 for the social sector, Ev-2 for the environmental sector, Ph-1 for the public health sector, and Eg-3 for the energy sector. Among all the fifteen factors, Ec-1 was given more importance. Prioritization of alternatives was obtained as renewable energy > waste and resources > clean mobility > nature-based solutions > green construction and retrofits > active transport. Investing in renewable energy remained on top while investing in active transport got the least ranking. Nevertheless, it does not mean that active transport is not important. It is only not a priority area for Pakistan at the moment. Whereas, it can be a top priority in any other country or region according to their need. Similarly, investing in renewable energy may not be the top priority of some countries which have already achieved substantial gain in it.

The current study is the first of its type, developing a framework that gives a simple yet effective practical answer to the complicated decision-making of “where to spend for the most sustainable revival of cities?” Unlike previous studies that just recommended multiple paths, our analysis prioritizes pathways based on their potential for reviving the economy’s primary sectors. The analysis begins by identifying sectors that require immediate revitalization. Later, via a thorough literature review, factors that can significantly contribute to the recovery of each sector were discovered. Pathways for sustainable recovery were also determined after evaluating recent scientific findings and discussing them with experts. The MCDM approaches ANP and VIKOR, which have a distinct advantage over other techniques, were employed for the analysis. ANP, for example, is more powerful than Analytical Hierarchy Process (AHP) because, unlike AHP, ANP first constructs a network of criteria, sub-criteria, and alternatives and determines their interdependencies before calculating weights and ranks. Similarly, only the VIKOR approach offers compromised options, which are significant in decision-making since an alternative does not always meet all of the criteria but is superior to others. VIKOR treats it as a compromise alternative, giving it precedence over others.

6. Conclusion

Building sustainable cities have become vital especially after watching cities breaking down effortlessly amidst the crisis. For this purpose, the current study presented a framework that can help decision-makers at the country, region, or city levels to choose areas for investment that can help build better, inclusive, green, and resilient cities. The framework can be applied to prioritize a range of areas based on factors important for the recovery of key sectors including economic, public health, social, environmental, and energy. In this study, the framework was applied to the case study of Pakistan. It was found that investment in renewable energy at the present has maximum contribution to the aim of revitalizing cities. The results of the study are valid for Pakistan only. However, the framework can be replicated for a similar purpose in studies conducted for any other country or region.

Supporting Information

Supporting Information is available from the Wiley Online Library or from the author.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Keywords

ANP, COVID-19, green recovery, smarter cities, sustainable cities, sustainable energy, VIKOR

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