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Maintaining the Sustainability of Critical Infrastructure

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Abstract

Critical infrastructures operations significantly affect the triple bottom lines of sustainability. Considering the dynamic nature of infrastructure and its surrounding environment, the interaction between them can dramatically change over time. This results in a deviation from the predictions used in the design and construction of the infrastructure. Therefore, the negative impacts of critical infrastructures on the environment, society, and economy can exacerbate throughout their service life. It is crucial to maintain these impacts within the desired limits. The measures that attempt to perpetuate a facility's adverse effects on the triple bottom lines of sustainability can be called sustainability maintenance. Regular maintenance operations of infrastructure create an opportunity to integrate sustainability maintenance into preventive, corrective, and periodic maintenances. This chapter discusses four categories of sustainability maintenance of critical infrastructures: (1) minimizing adverse impacts of the infrastructure on people through maintenance, (2) keeping the maintenance operations sustainable, (3) sustainable material allocation throughout the maintenance process, and (4) environmental protection and restoration in maintenance operations. In each category, some of the best practices and methods are discussed.

Keywords

critical infrastructure maintenance sustainability environment society economy

Chapter and author info

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1. Introduction

Critical infrastructures around the globe serve human beings in multiple aspects by supplying their essential needs for energy, water, food, healthcare, and transportation to name a few. These facilities are vital for the health, well-being, and economic growth of nations and are pivotal contributors to sustainable development. On the other hand, critical infrastructures can directly or indirectly affect the environment, economy, and society in a negative way [1, 2, 3]. For example, in the United States, almost 30% of all electricity is generated from coal. Coal power plants generate 42% of mercury emissions. This emission can damage the digestive, nervous, and immune systems, and is a critical threat to child development. While only 1/70th of a teaspoon of mercury deposited on a 25-acre lake can make the fish unsafe to eat [4]. As seen in Table 1, the EPA reports show that only in 2014, US coal plants generated 45,676 pounds of mercury [5].

				-				—	
Amount	45,676	3.1×10^6	1.5×10^6	197,286	41.2	9332	576,185	22,124	77,108

Unit	pounds	tons	tons	tons	tons	pounds	tons	tons	pounds

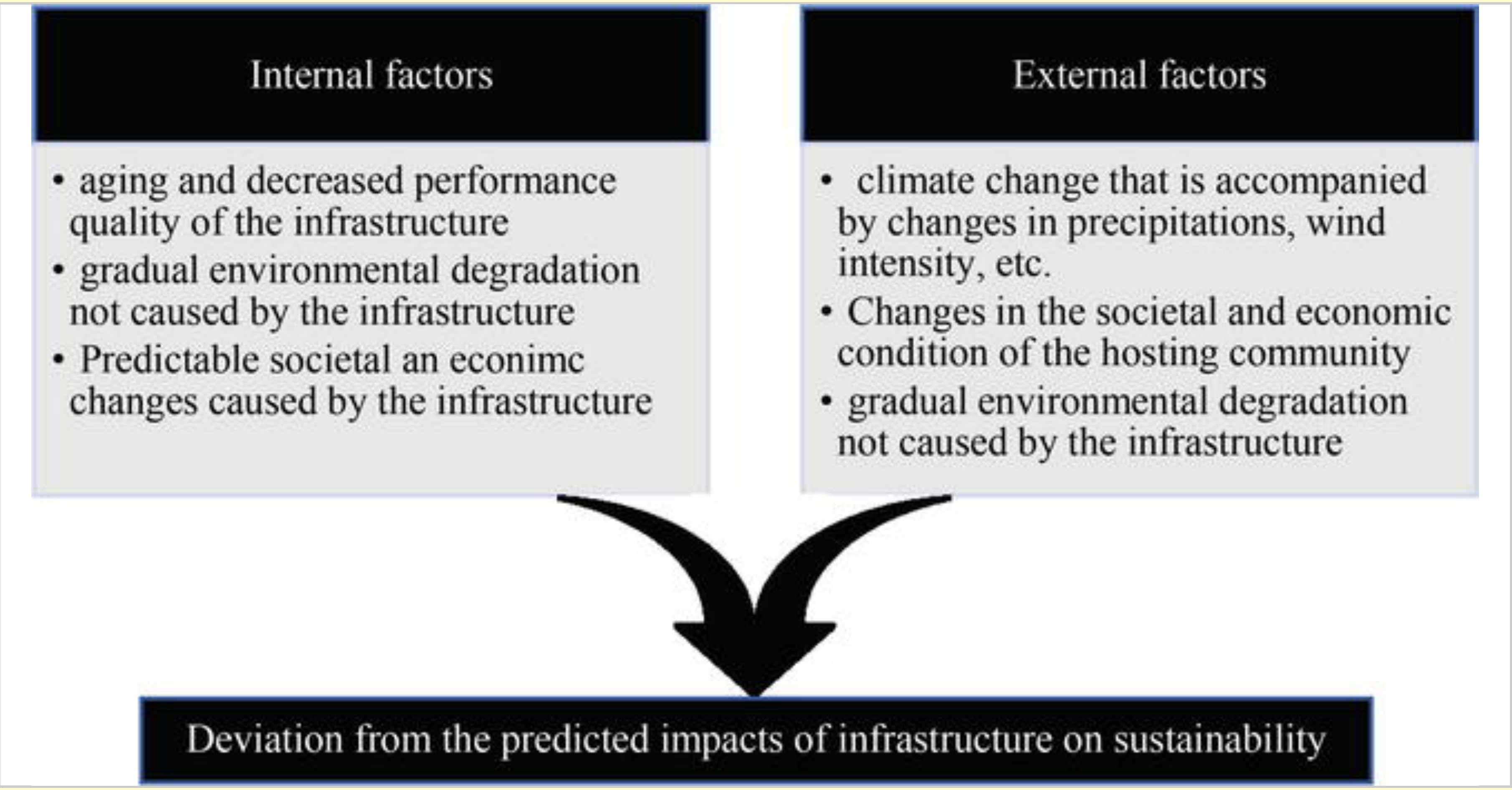
Pollutants created by coal plants in the in 2014 in the USA

* Particulate matter.

** Volatile organic compounds.

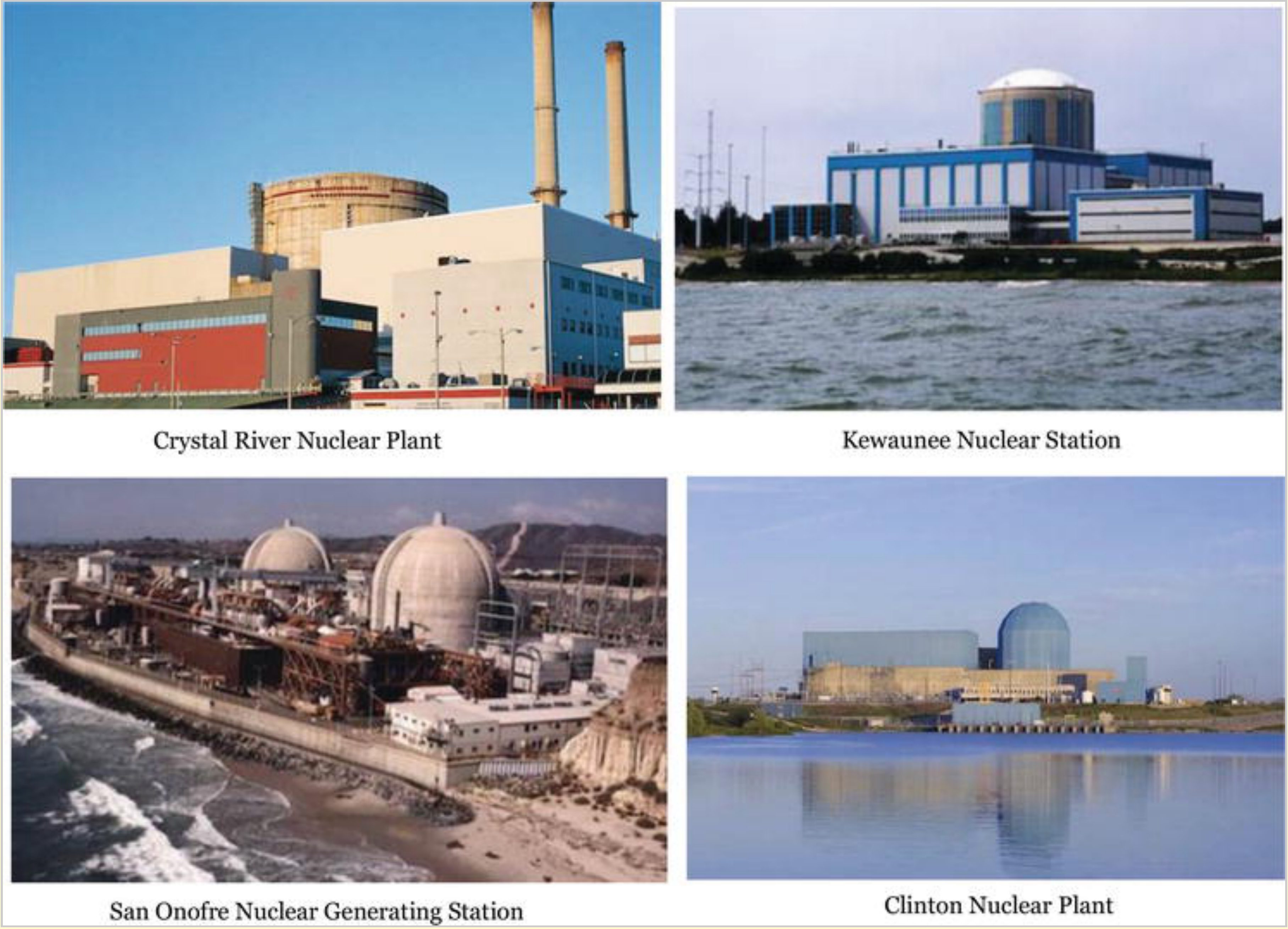
The negative impacts of critical infrastructure are not only environmental. The ripple effect of ecological degradation can significantly affect the health and well-being of human beings as well as the economy of the hosting community. For instance, in the example above the pollutants generated by the coal-fired power plants contribute to cancer, heart and lung diseases, neurological problems, and asthma, [4]. Additionally, the resultant acid rain can damage and degrade properties and affect the economy of neighboring areas.

Considering the immense impacts of critical infrastructure facilities on the sustainability triple bottom line [6], it is crucial to develop a comprehensive plan throughout the life-cycle of these facilities to maintain their sustainable performance. While these impacts are mainly studied and the strategies to control them are established at the pre-design phase [7], due to a large number of internal and external factors (see Figure 1), all the potential effects of critical infrastructure on the sustainability cannot be predicted until the facility starts its operation.



Factors causing a deviation from the predicted interaction of infrastructure with its surrounding environment.

The impacts of the critical infrastructure on the economy, immigration, ecosystem, and environment may take a direction different from the forecasted scenarios. Examples are the shutdown of four nuclear power plants in the USA (see Figure 2 and Table 2) which wasted billions of dollars from the taxpayers. The unpredictable aspects of infrastructure are primarily because many external factors that can impact the sustainability performance of infrastructure are not predictable. Additionally, the external factors can affect the tolerance of the hosting environment in dealing with the negative impacts. Hence, the sustainability maintenance plans of infrastructure must be updated to effectively respond to the changes and decelerate the sustainability deterioration of critical infrastructure.



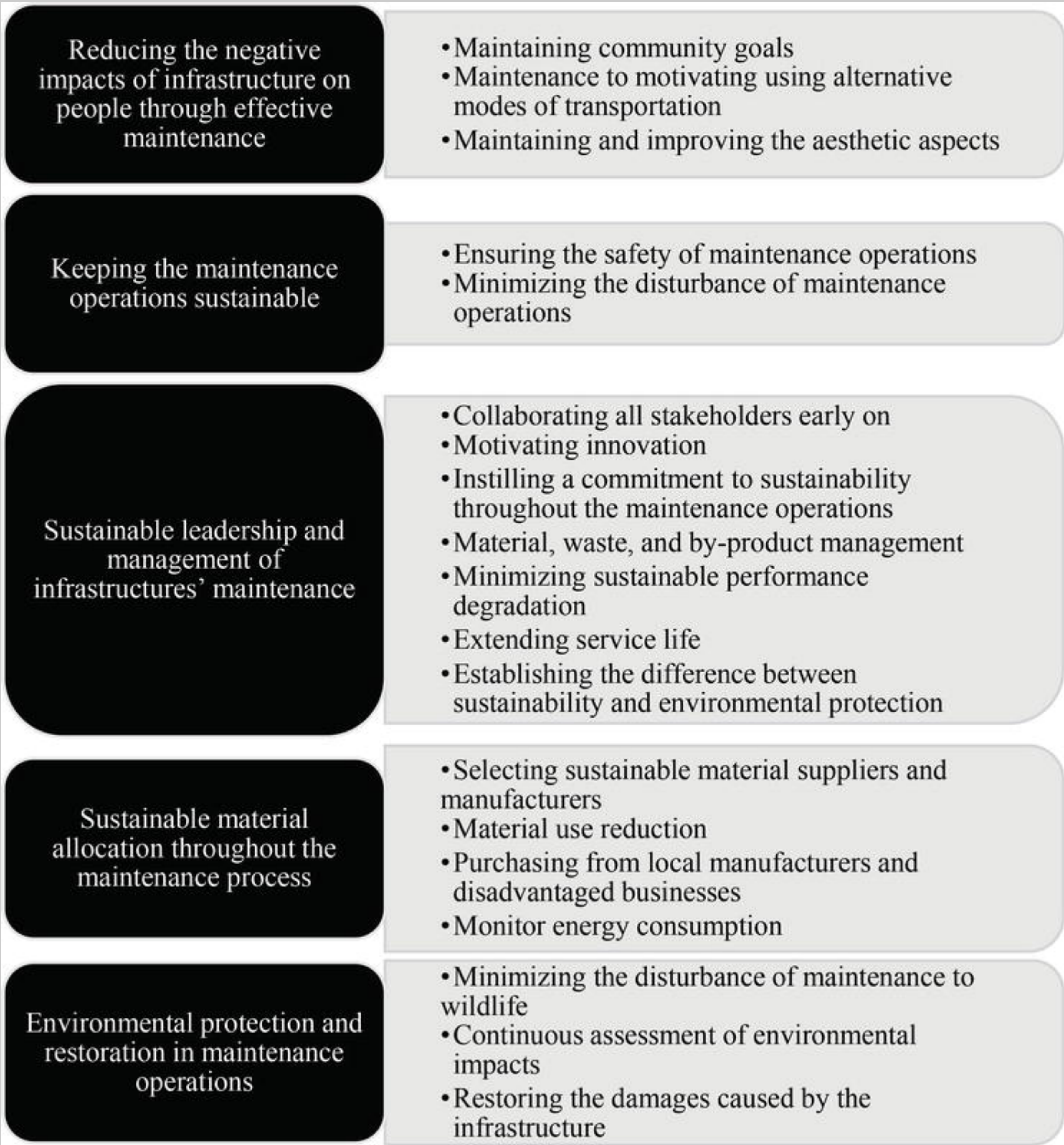
Four critical infrastructures shutdown in the USA [8].

Crystal river	Crystal river, Florida	March 13, 1977	February 5, 2013	High price of repairs ($3.44 billion)
Kewaunee nuclear station	Kewaunee Wisconsin	December 1973	May 7, 2013	No buyer for the plant
San Onofre Nuclear Generating Station	San Clemente, California	1968	June 2013	Long time-repair and high restart costs
Clinton Nuclear Plant	Clinton, Illinois	1987	June 1, 2017	Becoming extremely uneconomical

The reasons for the shutdown of some nuclear power plants in the USA [8].

2. Best practices to maintain the sustainability of infrastructure projects

This section discusses the best practices to maintain the sustainability of infrastructure projects during their service life. These practices are explained in five categories as it can be seen in Figure 3. In each category, the recommended policies and practices are sub-categorized and discussed. These practices can be applied to any infrastructure facility or specific ones. Facility managers, decision-makers, and maintenance operation personnel must understand the necessity of investing in the implementation of these practices and motivate other personnel to a collaborate effort for maintaining a high quality of service from the facility as well as minimizing the negatives impacts of the infrastructure on the triple bottom lines of sustainability.



Five categories of sustainability maintenance of critical infrastructures and their sub-categories.

2.1 Reducing the negative impacts of infrastructure on people through effective maintenance

Depending on the size, type, and location of critical infrastructure facilities they can potentially affect large groups of people. These people can belong to one of the following categories.

People who work at the facility (full-time employees).

People who live in the vicinity of the facility (neighbors).

People who regularly commute to the facility (clients).

The sustainability maintenance measures to protect the health and well-being of people who belong to each of these categories can vary. There are comprehensive safety instructions to protect the people inside the facilities (including personnel and clients). The following practices in this section are primarily focused on protecting the people who live in the vicinity of an infrastructure facility (group 2). It is essential to keep in mind that people's health is the tops priority of sustainable development and it cannot be compromised or put at risk.

2.1.1 Maintaining community goals

While an infrastructure facility is developed to serve the public, it can be detrimental to the hosting community goals. Consider this case: A power plant that was established decades ago in the proximity of some small neighborhoods, initially led to the creation of job opportunities and a considerable amount of immigration to this area. The small neighboring communities who live near this facility were pleased about the foundation of this power plant as the value of their properties increased dramatically due to the economic growth. The facility administrators are now going to extend the facility's production. Locals are against this decision as they may believe that the air pollution caused by the power plant has increased in the last few years. This can be attributed to an increase in the production of the plant that can lead to more pollution. The power plant is now a burden on the community as the area has sufficiently developed and people feel that it is creating more problems for the community than contributing to the local development. The enlargement of the existing power plant threats the community goals by diminishing the quality of life and vitality of the locals. This example explains how a sustainable facility can turn to be detrimental to community goals and values.

The maintenance process creates the potential to identify and fix the gradual deviation of the infrastructure from the community expectations and goals. The community needs to notice that their concerns are considered and their voice is heard by the infrastructure's decision makers [9]. In order to meet the community's concerns people or their representatives must be involved in the decisions. Different tools can be used to communicate with the community and hearing their concerns. Survey questionnaires can particularly be helpful when the decision makers have to select between different requests by the public to figure out which options are more vigorously requested by the public. Communicating with stakeholders and inviting them to meetings to express their concerns about the issues caused by the facilities that can be mitigated through maintenance is another possible solution to engage people.

Another critical consideration in the assessment of the community issues and concerns and incorporating them into the maintenance plans is the conflict of interest between different communities [10]. This happens when one community benefits from a decision while another community finds it detrimental for its common goals. In these situations, hearing people's voice and their concerns can lead to informed decisions that more effectively address the concerns of the affected communities (Figure 4).

Best practices to maintain community goals throughout the service life an infrastructure facility.

2.1.2 Maintenance to motivate using alternative modes of transportation

Many critical infrastructure facilities are extended to meet the growing demand of the hosting community for the type of service they provide. As a result of this extension, more people need to commute to these facilities as full-time employees or clients. The maintenance of critical infrastructure creates an opportunity for motivating people to use alternative modes of transportation (such as walking or using bicycles) to commute to the facility. This is particularly important for infrastructures with a high number of visitors and employees such as commercial facilities. Some suggested policies are listed below [11].

- Assigning priority parking for hybrid vehicles.
- Creating facilities to use bicycles (parking spaces for bikes and shower rooms for the drivers).
- Using gulf cars for the trips within the facility.
- Installing electricity charger in parking for electric vehicles.
- Improving access to public transit.

2.1.3 Maintaining and improving the esthetic aspects

Considering the magnitude of many critical infrastructures, and their long service life, the appearance of many of these facilities deteriorate, and if they are not maintained, they can become the eyesores of the hosting community. This can indirectly impact the neighboring areas and decline their property value. The maintenance must preserve the attractiveness of the community to live and work through the application of different measures that can enhance the appearance of the infrastructure facility. Some examples of performing this are using barrios that can mask an unpleasant view or renewing the paint, fixing the fences, and taking advantage of advertisements on old looking walls or other surfaces.

2.2 Keeping the maintenance operations sustainable

The maintenance process of critical infrastructure can involve heavy construction or lengthy operations with a lot of potential negative impacts on different aspects of sustainability. Since one of the primary purposes of the maintenance measures is improving sustainability performance, it is crucial not to compromise sustainability during the maintenance process. Some of the measures for keeping the maintenance operations sustainable are explained in the following.

2.2.1 Ensuring the safety of maintenance operations

Many infrastructure maintenance activities involve risks for the people who work in the project or who live in the project's proximity [12]. Hazards involved in construction or maintenance of infrastructure facilities could be even more than typical (non-infrastructural) facilities as most of them are unique, extensive, and challenging to identify the potential risks during the maintenance operations. As an example replacement of cables of the Golden Gate Bridge requires working at the 746 above the water level where rain and wind are common. At such condition safety measures to protect the laborer from falls is essential.

The hazards of maintenance operations can pose risks to the public too [12]. Trench collapses and scaffold collapses are some examples. Proper site fencing is one of the major preventive measures. The public can find watching the maintenance operations, such as replacing a segment of a street bridge, interesting. The crowd gathered around a maintenance site is a potential risk that must be handled. In many cases, the movement of large construction equipment, particularly when exiting the site, can cause the risk of accidents with other vehicles, buildings in congested urban areas, and pedestrians. There are comprehensive safety measures in each country to protect the public against these hazards. Any negligence or underestimating the importance of cautiously implementing safety measures must be eliminated throughout the entire maintenance operations.

2.2.2 Minimizing the disturbance of maintenance operations

Many maintenance measures can potentially create a lot of dust, noise, road closure, traffic congestion, odor, power outage, vibration, light pollution, and other problems to the community. It is essential to ensure that such disturbances are minimized. Some suggested policies are listed in Figure 5.

Best practices to minimize the disturbance of maintenance operations for the neighbors.

2.3 Sustainable leadership and management of infrastructures' maintenance

A large number of factors are involved in sustainability [13]. Examples are people and their health, well-being, and vitality; planet and the impacts of pollutions, energy consumption, and depleting resources on wildlife and habitat; and the economy with its connections to industrialization, and growing demand for more raw materials and disturbances in nature [14, 15]. This means that a great deal of interdisciplinary knowledge and expertise are required to make a sustainable decision. Additionally, every decision has its tradeoffs that need to be evaluated, and it can be challenging to decide what to compromise in the hope of gaining something that is more crucial to the public. The term public in this context is not only the people who might be impacted by that decision; it also spans to future generations [16]. The pressure of profitability almost always amplifies this complexity as it is a powerful incentive for decision-makers to accept the downfalls of a decision in the hope of economic growth.

While the concept of sustainability seems to be a straightforward approach for most people, due to its comprehensiveness and the conflicts of interests which it inherits, it requires a lot of leadership and management. Some of the best practices of sustainable management of infrastructure are discussed in this section.

2.3.1 Involving all stakeholders from Early Stages

While the need for the collaboration of stakeholders in decisions seems to be obvious, the significance of their early collaboration might not be sufficiently noticed. People, particularly, must be involved before decisions are made to ensure the concerns of the community are adequately considered in the decision making process [17]. This can be done through the managers' determination to integrate the public's demand and concerns in the decisions and involve experts from different disciplines to come up with optimized decisions. It is crucial to keep in mind that maintenance provides an opportunity to adjust and change an existing infrastructure based on the actual issues observed during its operation.

The public's engagement should not be considered an additional challenge for the project. Reflecting the public's input in the project is an essential factor in coming up with the decisions in which the public's concerns are considered, and negative impacts on the hosting community are minimized. This requires building a relationship with the key stakeholders. Although in some regions there are regulations that enforce the involvement of the public, the sustainability goals go beyond fulfilling the minimum required standards and seek for active engagement, transparency in notifying the public about potential impacts and incorporating them in the process of decision making.

Managers must facilitate communications using all the possible tools. While many maintenance projects are composed of the involvement of multiple independent entities who are primarily focused on delivering their portion of work, managers must minimize isolated thinking and establish a collaborative approach in which impacts on sustainability can be easily communicated between different project players. Similar to integrated project delivery in construction, the maintenance operations should also attempt to reach to an optimized collaborative environment from the start point. This approach is in contrast with the traditional methods in which project parties prefer to work separately. The managers' determination and attempt to change the independent work environment to a collaborative work environment is essential in the success of sustainability plans in an infrastructure maintenance project.

2.3.2 Motivating innovation

The maintenance management team must promote any changes in the existing maintenance strategies that can potentially improve sustainability. An effective change is utilizing new technologies for data collection. The amount and quality of data about infrastructure are closely linked with the quality of maintenance. Management must establish a culture of "change for the better" in the maintenance team to seek for any modifications in the existing maintenance policies that can lead to improvement. This improvement can be about cutting the maintenance costs, improving the quality of the infrastructure serviceability, or enhancing the sustainability of maintenance operations to name a few.

2.3.3 Instilling a commitment to sustainability throughout the maintenance operations

The management's commitment to sustainability is pivotal in promoting or discouraging sustainable approaches among all team members [18]. The managers must make sure that the team has a sufficient understanding of the threats of all the maintenance operations to sustainability and work effectively with them to minimize these threats. This commitment must be observable in the design, schedule, field activities, and inspections. The team must be aware that the management has no willingness in compromising sustainability for less critical goals such as performing the operations more quickly, or cutting the costs unless they can be justified in a sustainable-thinking context. Sustainability workshops before beginning the maintenance operations are often needed to transfer the determination of the company to contribute to sustainability to the project players as well as teaching them the best practices that trigger sustainability.

Commitment to sustainability must be established as a subject that is as important as safety. While this may seem exaggerated for some contractors, they can understand it better considering that unsustainable methods can potentially impact the health or well-being of communities at local, national, or even international levels, while unsafe operations mostly pose risks to the staff on the job site or the neighbors only. Moreover, since protecting the health of human beings is an indispensable element of sustainable development [14], improving the job site safety perfectly lines up with the goals of sustainability [19]. Combining safety and sustainability workshops are expected to contribute to instilling a crucial need for sustainability among the maintenance team.

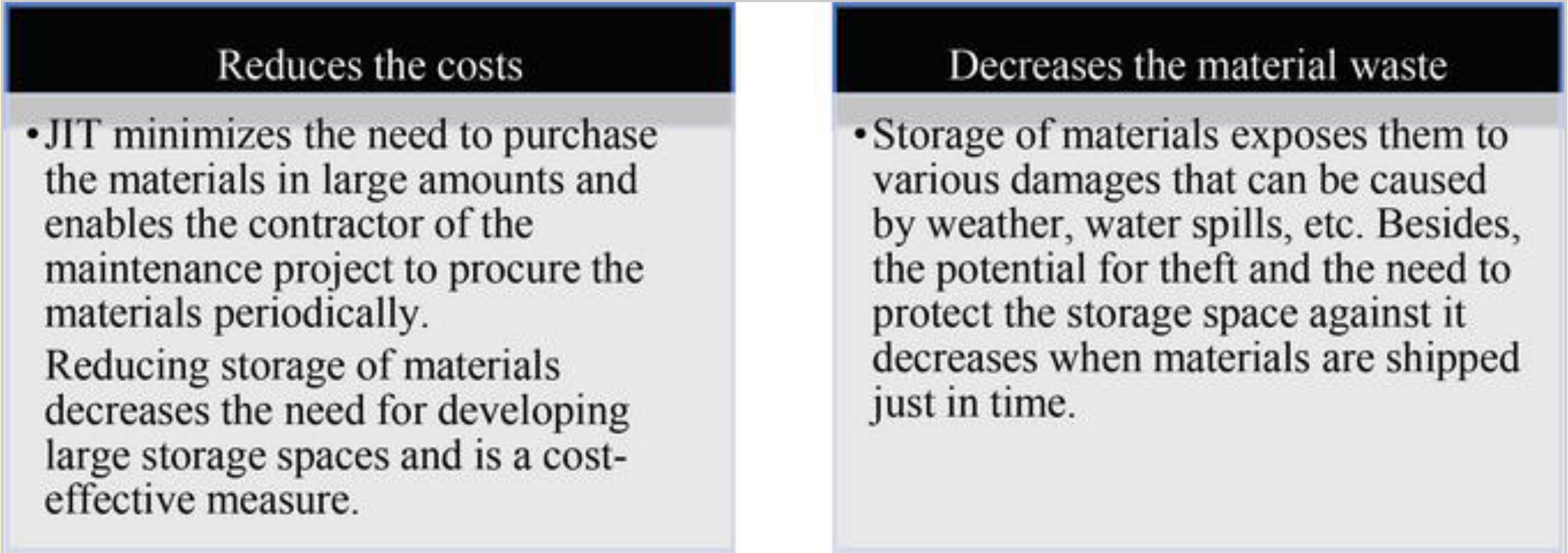
Some of the potential impacts of the maintenance operations on the hosting environment can only be noticed during the operations. Therefore, throughout the operations, the management team is responsible for supporting any decision or activity that can enhance the sustainability of the operations and achieve a level of sustainability that is beyond the original plans.

2.3.4 Material, waste, and by-product management

Although material, waste and by-product handling is a team effort, the management role in leading the team is substantial. Material handling aims at maximizing the efficiency of the construction and maintenance materials. There are various methods and best practices to implement it. Some highly recommended tools are briefly explained in the following.

Just-in-time (JIT) procurement of materials which attempts to minimize the need for storing materials and bringing them to the site when they can be almost immediately used in the maintenance operations. The advantages of JIT material procurement is shown in Figure 6 [20].

Waste management workshop for the team. There are a lot of potentials for effective management of waste and by-products in a maintenance project. Project-specific opportunities for reduction of waste, reuse, recycle, convert, or compost must be identified by the managers or their representatives. Laborers should receive adequate instructions about the firm's waste management policies and be motivated to contribute to it.



Advantages of shipping the material to the facility Just-In-Time.

2.3.5 Minimizing sustainable performance degradation

It is often observed that sustainability concerns are usually centered to the facility's design and construction phases (rather than the operation phase) and once an infrastructure facility starts operation, the focus of its managers is maintaining its level of service at the expected quality and. This explains why the negative impacts of a facility on sustainability becomes more noticeable in the course of its service life. Another reason for sustainable performance degradation are populist managers who make decisions to pretend their attention to sustainability, while they refuse to accept the sustainability costs that people or media will not necessarily notice or appreciate.

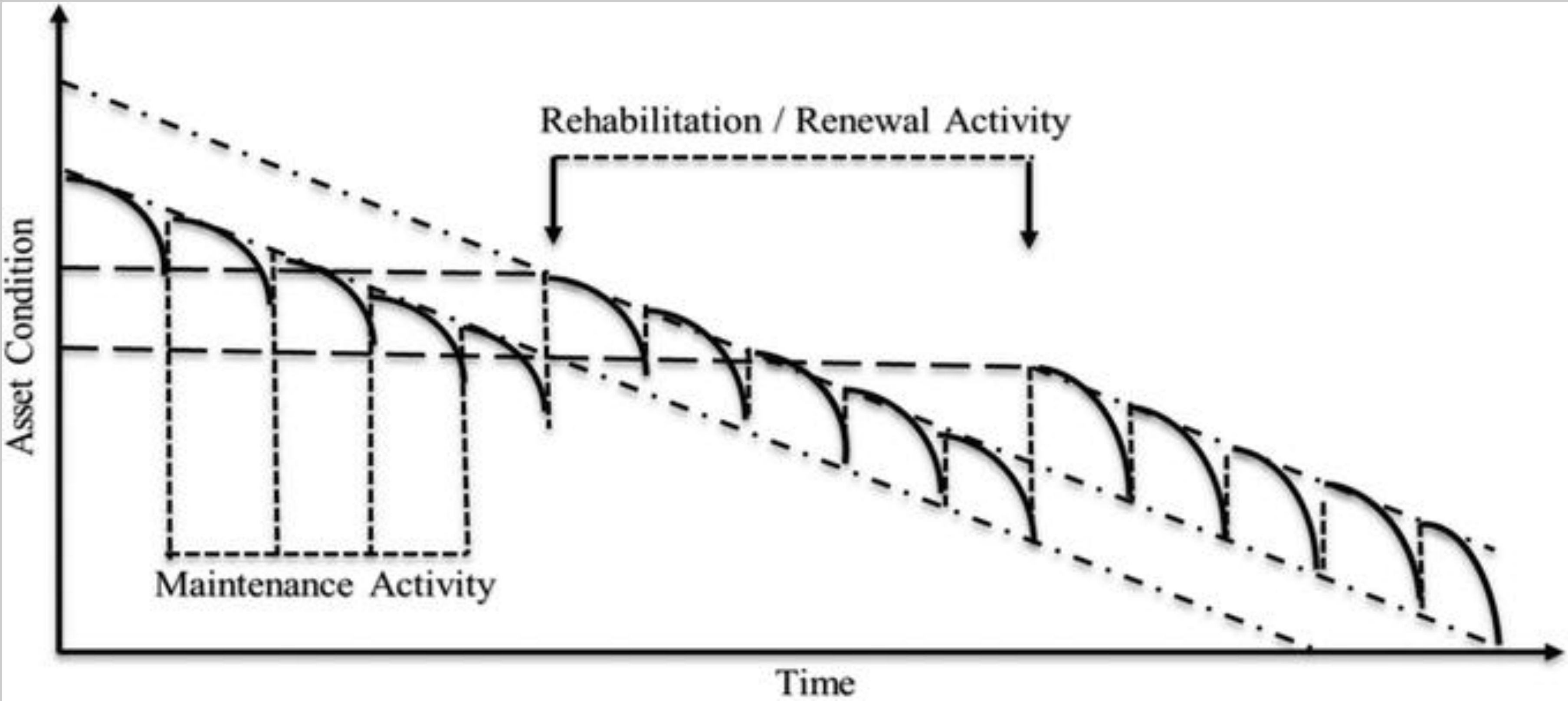
Maintenance operations are primarily focused on replacements that can improve the serviceability or durability of a facility. Less attention is commonly paid to fixing the sustainability issues. Although infrastructure projects are often designed with careful examination of the potential impacts of the facility, due to the dynamic nature of the surrounding environment and other modifications in the facility in the course of its service life, many sustainability issues may arise when the facility is in operation. Managers have a critical responsibility to continuously measure and mitigate the sustainability threats of the project. Maintenance for sustainability can encompass low-cost activities such as eliminating the noise caused by displacement of a utility hole cover to more intensive maintenance such as restoring the vegetation affected by the pollution. The target is to maintain the infrastructure surrounding in such a way that the facility's footprint is almost none beyond its shell. This requires a specific focus in maintenance that is supported and pursued by the managers.

What makes maintaining sustainable performance more challenging are the changes in the management team. Different managers have different priorities in mind that can impact their determination for maintaining the facility's sustainability. A useful tool that can prevent underestimating sustainability in maintenance policies is developing a comprehensive long-term plan for sustainable performance that can be pursued by future managers. On the other hand, relying on old approaches inherited from previous managers is not helpful as the project's impacts, and the demands for environmental protection can change. The managers must, therefore, seek solutions for improvement while staying committed to the long term plans of sustainable maintenance.

2.3.6 Extending service life

The development of an infrastructure facility is often the product of the monetary contribution of a large number of taxpayers. Some of the infrastructure facilities also require a lot of compromises due to their adverse impacts, particularly on the environment. Therefore, it is crucial to make every effort to extend infrastructures' service life as much as possible.

A great deal of a project's service life depends on the quality of its design. Flexible design enables the project to respond to the variations in public's demand from the facility, and the dynamic changes of the facility as well as the external factors it interacts with. The design must allow reconfiguration as well as refurbishment of the facility and minimize the need for demolition or replacements. Additionally, the design must establish a high resiliency in the facility to survive against the external pressures. Though, even with a perfect design, the facilities will gradually start to deteriorate. As can be seen in Figure 7 [21], two main approaches can be applied to extend the service life of infrastructures, maintenance and rehabilitation. Both approaches primarily depend on budget and project condition. Maintenance is done in shorter intervals, and higher frequencies improve the asset condition [22]. When regular maintenance activities cannot effectively improve the asset condition, a rehabilitation or renewal activity must be pursued. This requires more time, budget, and effort but, as they can be seen in the graph, can more significantly improve the infrastructure condition. In this figure, the distance between the two parallel diagonal dotted lines on the x-axis indicates the added time to the service life as a result of maintenance and rehabilitation.



Extending infrastructure service life through maintenance and rehabilitation/renewal.

Facility managers must be mindful about a load of service on the facility even though it is below the capacity. A higher load of operation is linked with quicker deterioration. The manager should keep close attention to avoid over-production to lower the unnecessary load to the infrastructure. Setting various inspection intervals depending on the frequency of the need for repairs in different components of a facility is another helpful approach. Long inspection periods for all components is detrimental to effective maintenance which is geared towards extending the facility's service life and must be avoided.

2.3.7 Establishing the difference between sustainability and environmental protection

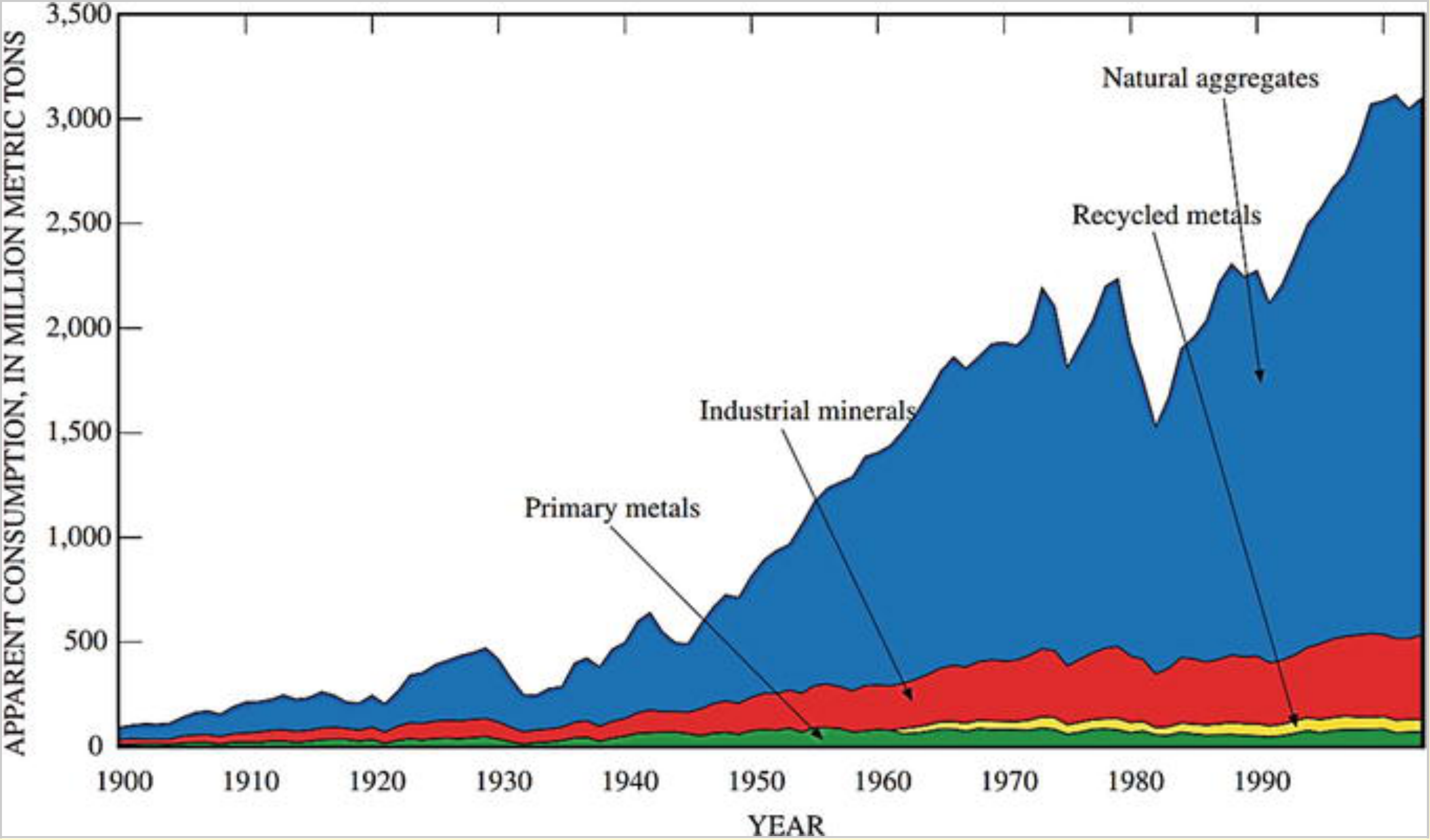
Although environmental protection is a critical goal of sustainable development, it is essential to understand that sustainability goes beyond environmental protection and involves social and economic goals. The establishment of this understanding is the responsibility of the managers. This can be challenging because understanding the potential threats to communities can be more complicated than figuring out the environmental threats. Some maintenance decisions may not have negative environmental impacts, but they may be detrimental to the society or economy.

Here is an example of the necessity of paying attention to the social aspects of sustainability besides the environmental aspects. Consider a coal plant with a private access road that is far enough from a residential neighborhood. While developing the maintenance plan, the plant's manager suggests relocating the access road to the neighborhood nearby that has a low population can save the travel time for the trucks that supply the materials for the plant. The decision seems to make sense from the environmental aspect as it saves a few minutes of travel time and can potentially lead to a reduction in the pollution caused by the trucks in the long run. However, it will impact the people living in the small neighborhood on a daily basis. Therefore, if environmental protection is the sole criteria for making a sustainable decision the social and economic aspects of sustainability can be compromised, and this defeats the purpose of sustainable development.

It is essential to establish equity in pursuing sustainability [23] Equality in sustainability can be defined as being impartial to the communities while making decisions that can impact the triple-bottom-line of sustainability in neighboring areas. Lopsided progress in sustainability programs by putting one community prior to another is in contrast with sustainability goals. Bearing in mind that trade-offs are inherited in many decisions tied to development, the community facing the consequences of a decision may be different from the community that benefits from it. Keeping the balance between neighboring communities in benefiting from the opportunities promotes sustainable development.

2.4 Sustainable material allocation throughout the maintenance process

Growing concerns about depletion or shortage of resources, in addition to increasing demands for more materials, explains the necessity of efficient resource allocation [24]. Depending on the type of infrastructure and the depth of the maintenance operations, the volume of required materials for the maintenance can vary from small amounts to enormous quantities. For example, tons of concrete can be required in the replacement of a bridge segment. The way these materials are selected, shipped, and used in the maintenance operations have impacts on the triple bottom lines of sustainability. According to the World Counts, on average everyone uses 16 kilos of resources extracted from the earth every day, and for people in the western world, this number is much higher—up to 57 kilos of newly-mined minerals per day [25]. Based on the United States Geological Survey (USGC) the U.S. apparent consumption of raw materials at the beginning of the century has increased more than six times from 1940s (see Figure 8). The infrastructures are massive consumers of resources worldwide. For example, a total of approximately 1.5 billion tons of aggregates, 35 million tons of asphalt, 48 million tons of cement, and 6 million tons of steel is in place in interstate highways of the USA [25].



U.S. apparent consumption of raw materials (courtesy of USGS).

In addition to the depletion of resources, transportation and shipping of raw materials can affect the environment in multiple direct or indirect ways. The massive amount of construction materials that were mentioned in the example above must be transported to sites through thousands of trips by heavy equipment that contributes to air, water, and noise pollution as well as fuel consumption. The indirect effects of trips to supply the materials for the infrastructure can indirectly contribute to global warming, climate change, and threaten the health of human beings. Additionally, continuous traffic of heavy equipment to an infrastructure (such as plants and refineries) will have impacts of the property value of the surrounding neighborhoods and affect the economy bottom-line of sustainability.

These examples indicate that any improvement in the way the infrastructure materials are procured is expected to significantly contribute to sustainable development.

2.4.1 Selecting sustainable material suppliers and manufacturers

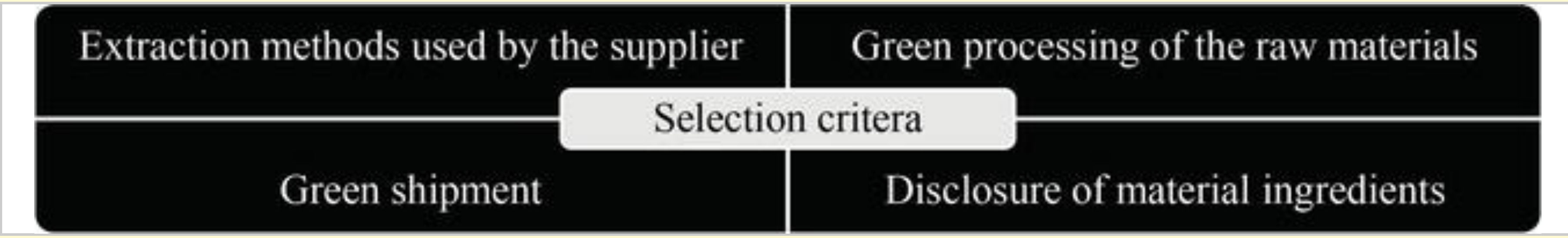
Purchase of materials is commonly done through bidding and choosing the least expensive bidder that meets the expected quality. Less attention is paid to how sustainably the supplier or manufacturer procures the material. Selecting the material supplier is a multi-criteria decision [26, 27]. Selection criteria of material supplier or manufacturer must modify and include the following criteria (Figure 9).

- Extraction methods used by the supplier. This explains the policies the manufacturer uses in extraction to maintain the balance of resources in nature and what measures they utilize to minimize the negative impacts on the ecosystem. There are six principles of green extraction [28]: 1) using renewable plant resources, 2) using alternative solvents, 3) reducing energy consumption by energy recovery, 4) converting wastes to co-products, 5) reducing unit operations, and 6) maximizing non-denatured and biodegradable uncontaminated extracts.

- Green processing of the raw materials. This defines how sustainably the extracted materials are processed by the manufacturer. There are multiple criteria to measure this. Some of these criteria are as follows: (1) Compliance to physical safety (safety measure regarding flammability, explosivity, corrosion, oxidation, and radioactivity), (2) compliance to air pollution reduction (meeting the allowable impacts on air, water, and soil), and (3) sustainable waste management (waste generation reduction, green recycling methods, recyclability of products).

- Green shipment. This defines the measures the manufacturer utilizes to minimize the pollution generated in the shipping process. Some criteria to measure this are as follows: (1) using low polluting vehicles and (2) efficient shipment design (to minimize the number of trips).

- Disclosure of material ingredients. The supplier must disclose the life-cycle information of the chemicals they have used in the product. This is more important for the infrastructure facilities that are in the proximity of children or other sensitive groups.



Selection criteria of material supplier or manufacturer.

2.4.2 Material use reduction

The maintenance operation must seek for minimizing the need for raw materials. This can be achieved without compromising the quality of maintenance if certain measures are taken collaboratively. Some of these measured are explained in the following.

- Using recycled materials. Using recycled, reused, and renewable materials reduces the demand for raw resources and contributes to preserving them for future generations. Maintenance operations that involve reconstruction of segments have high potentials to reuse certain elements of the existing part that is demolished. This requires an assessment of the opportunities to reuse and planning it before the demolition starts. Additionally, repair policies instead of replacement, particularly for equipment pieces, can significantly contribute to saving the embodied energy that has been used to manufacture, ship, and install the existing equipment. However, in all cases, the quality and performance criteria must not be compromised.

2.4.3 Purchasing from local manufacturers and disadvantaged businesses

Procurement of materials from local suppliers lines up with sustainability goals in two ways: (1) by supporting the local businesses and contributing to economic growth and the welfare of the local community and (2) by reducing the negative impacts of shipment of materials on sustainability (air pollution caused by the shipping vehicles, costs, and risks of road accidents).

In addition to local suppliers, the disadvantaged businesses must be supported while selecting the suppliers, or manufacturers. In the U.S. public projects, there is commonly a specified minimum percentage of purchases that must be obtained from the disadvantaged businesses. Examples of these businesses are African Americans, Hispanics, Native Americans, Asian-Pacific and Subcontinent Asian Americans, and women-owned companies. Considering that most infrastructure facilities are public, maintenance purchases that are often in smaller amounts compared with new construction purchases creates an opportunity to support disadvantaged business although these businesses may not afford to be the lowest bidder.

2.4.4 Monitor energy consumption

One of the purposes of infrastructure maintenance must be maintaining the infrastructure's negative impacts within the decided limits throughout the service life of the facility. For an operating infrastructure facility, a large amount of these impacts depend on energy consumption rates. The energy performance of infrastructure facilities is expected to decline throughout the years of service. Maintenance must fix the degradation of energy performance. This depends on the quality of energy monitoring that enables the facility managers to identify were the energy losses are occurring and fix them.

2.5 Environmental protection and restoration in maintenance operations

Although infrastructure projects are often designed and constructed by studying and minimizing their potential impacts on the environment, due to a variety of mostly unpredictable causes, these facilities can cause different damages to the neighboring areas. It is essential to include the protection and restoration of such damages in the maintenance policies. The degradation of nature happens gradually, and the damages can be difficult to notice without inspections.

In Addition to restoration, the causes of the damage to nature need to be studied, and preservation from further damage must be added to the maintenance programs of the infrastructure. For instance, if soil pollution has been reported, different possible scenarios of the causes of pollution need to be considered. The common practice in such cases is relying on the most obvious cause for the damage while further assessment can reveal some causes that may seem unlikely. The comprehensiveness of the assessment has a central role in the quality of maintenance programs.

Infrastructure facilities affect the surrounding environment in various ways. Although some compromises about the negative environmental impacts are inevitable, taking certain measures can significantly reduce these impacts. The majority of the environmental protection activities are related to the design and construction phases; however, the maintenance policies of infrastructures can contribute to effectively preserve its surrounding environment. What follows are some of the methods to enhance environmental protection while the facility is operating.

2.5.1 Minimizing the disturbance of maintenance to wildlife

Depending on the facility's location, the maintenance operations can disturb wildlife in different ways. While a lot of consideration is commonly given to minimizing the disturbance to wildlife during the construction process, the risks of maintenance operations on the environment are, in many cases, underestimated and this can create severe threats for the habitats and wildlife. These risks are increased when wildlife is exposed to them for longer durations. This exposure can even impact migration, feeding, and breeding patterns. For instance, using vibrators in maintenance operations of a dam can affect the fish reproduction in adjacent waters.

EPA provides comprehensive guidelines and requirements [29] to ensure that maintenance operations' disturbances to wildlife are minimized. Some primary measures in doing so are listed in the following:

- Identifying vulnerable species in the project vicinity (including species sensitive to noises or vibrations, species that need large habitats, and species with low reproductive pedigree).
- Maximizing off-site operations (instead of performing the tasks on an eco-sensitive site).
- Minimizing different pollution types (air, water, soil, noise, and light pollution). Depending on the type each of the mentioned pollutions requires taking multiple measures for prevention.
- Establishing stringent fire-protection measures and regulations (for transferring and storing flammable materials, equipment fuel procurement, and smoking on the site).
- Restoring the changes on the natural habitat during after the operations (removing temporary equipment access roads by replacing the polluted or compacted soil with the natural soil of the area, restoring the damages vegetation and views.

2.5.2 Continuous assessment of environmental impacts

Depending on the type, size, and location of the infrastructure it can affect different elements of the natural world including habitats and species. The interactions between the facility and its surrounding environment can vary over time because both the infrastructure and the environment are dynamic systems with altering elements that interact with the elements of one another. For instance, the amount of pollution infrastructure generates can change based on its production. On the other hand, the tolerance of the adjacent environment can also modify based on the severity and frequency of rainfalls, the intensity of winds, and temperature inversion in different seasons or years. Another example is the tolerance of water bodies to pollutants which decrease as they are exposed to more contaminants. In this situation, the infrastructure may have to reduce its production to maintain the water quality before other preventive measures can be implemented.

The environmental assessment methods, required tools, intervals of measurement, and data analysis methods depend on the type of environment that is in the proximity of the infrastructure. Figuring out the pattern of the repetitive alterations in the reactions between the infrastructure and the responses from the environment can significantly improve the preventive measures.

2.5.3 Restoring the damages caused by the infrastructure

Paying adequate attention to preventive measures is essential in the management of infrastructure. Though, considering the complexities and unpredictability involved during long years of service of infrastructures some damages to the adjacent environment are inevitable. However, these damages can be minimized by executing restorative measures. Depending on the type of damage, a wide variety of options exist for restoration purposes. It is crucial to keep in mind that some of these damages cannot be readily observable and they require a more in-depth examination of the area and evaluation of the facility's impacts.

Restorative measures are focused on bringing the adjacent environment back to the condition it had before the infrastructure was developed, as much as possible. These measures are more critical when the damages affect residential areas, wildlife, habitat, rare species, greenfields, wetlands, prime farmlands, and historical sites.

The restorative measure can have different types depending on the type of damages they try to restore. Some of the main types are the following:

- Emergency restoration. This is when the damage should be taken care of immediately. For examples the leakage of pollutant fluids. The facility must develop a plan with the collaboration of different organizations to react quickly when such damages occur. In the case above, after the leakage is stopped, immediate action is required to remove the spilled fluid before the contamination transfers to lower layers of soil or a water body.

- Restoring the damages of a fire or smoke. One of the most critical impacts of infrastructure on the environment is increasing the risk of fires. Adequate preventive measures must be taken to mitigate the risk of fire transfer from the facility to adjacent areas. In addition to these measures, in case a fire happens, the damages it has caused must be restored by recreating the affected vegetation or removing the soot, water used in extinguishing the fire), and odor. In cases that restoration is not possible, the surface area and types of damages must be measured, and an equal amount of vegetation must be planted in an alternative site.

- Restoring disturbed soil. Natural soils are affected by the infrastructure in two major ways: (1) oil and other pollutants' spill and (2) compaction of soil as a result of temporary traffic of heavy equipment. Some maintenance operations utilize heavy equipment pieces that pollute and compact the natural soil. The facility managers tend to keep the temporary access roads in case a need arises in the future. This approach must be avoided as it unnecessarily expands the footprint of the facility.

In almost all restoration activities, promptness goes a long way and delaying the fixes can lead to irreparable damage. The key to prompt restoration is thinking ahead and having the required plans ready to step in when the need for restoration urges.

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3. Conclusion

Critical infrastructures have significant adverse impacts on sustainability that, if not handled, can defeat their purpose of serving to the public. Although a lot of attention is paid to develop a critical infrastructure with a minimal footprint, once a facility is operating less consideration is paid to evaluate how it interacts with its surrounding environment or the host community. It was mentioned that the dynamic nature of the infrastructure and its hosting environment causes a lot of alterations in how the facility impacts its surroundings. Examples such as the shutdown of nuclear power plants in the USA indicate that in many cased the planned trajectory of infrastructure may not be pursued due to various internal and external factors that affect infrastructures. Without proper maintenance of sustainability performance, the negative impacts of infrastructures will gradually accumulate and may lead to irreversible damages. Continuous data collection, inspections, and measurement of the environmental impacts are essential to identify how the facility's performance must be modified to maintain its negative impacts within the desired limits.

Sustainability maintenance is an ongoing process throughout the service life of infrastructure to maintain its negative impacts within the desired limits and ideally enhance its sustainability performance. It was mentioned that regular maintenance operations provide a significant opportunity to mitigate the negative sustainability impacts of infrastructure. Unlike the design phase in which the sustainability threats are predicted, while performing the maintenance operation, most of the sustainability-related issues are precisely identified.

The significant roles of considering the hosting community's concerns, managers' determination to sustainable performance, sustainable handling of materials, sustainable maintenance operations, and continuous restoration of damages caused by the infrastructure were highlighted.

https://www.intechopen.com/online-first/maintaining-the-sustainability-of-critical-infrastructure

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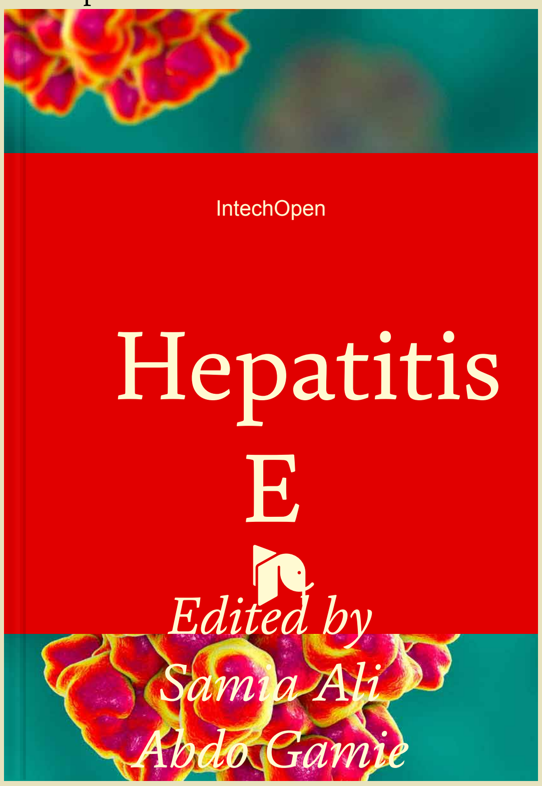

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