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*Original Research*

# A Hybrid BSC-CPM Model for the Improvement of Waste Utilization and Management Processes

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## Abstract

Waste disposal sites significantly contribute to the degradation of primary environmental elements. In the Republic of Serbia, these waste disposal sites have been generated due to improper management of materials that are recyclable to varying degrees. Municipal waste disposal has led to issues such as contamination of surface and groundwater flows and a decline in the quality of agricultural crops. Current environmental management systems lack high levels of efficiency; preventive protection measures are not fully implemented, and corrective actions are frequently hindered by a lack of financial resources. Problem resolution is often limited to the application of "carpet-like" grass covers over degraded landscapes. The aim of this paper is to propose a model for overcoming these ecological issues. The proposal is based on a phased implementation, transitioning from simpler to more complex methods. Challenges associated with the direct application of modern reclamation methods include a shortage of professional personnel, financial constraints, and a lack of institutional readiness among the management of mining and energy complexes. The proposed environmental management system model for municipal solid waste landfills is based on Balanced Scorecard (BSC) and Critical Path Method (CPM) guidelines. By offering clear, efficient, innovative, and progressive strategic perspectives, this model establishes a robust foundation for multi-criteria decision-making and a multidisciplinary approach.

**Keywords:** environmental protection, management, decision-making, multidisciplinary approach, municipal solid waste landfills, reclamation

## Introduction

There are 10 regional and 2 local sanitary waste disposal sites [1, 2] in the Republic of Serbia. These represent sanitary and technically regulated sites where waste is disposed of in accordance with legal regulations. However, the problem is that waste is still being disposed of at non-sanitary landfills (Fig. 1), and in 2024, a total of 119 such landfills were registered [1]. These are sites designated for municipal waste disposal by decisions of city and municipal authorities. Most of these landfills have reached their full capacity and do not meet technical standards. They harm the environment, especially when located less

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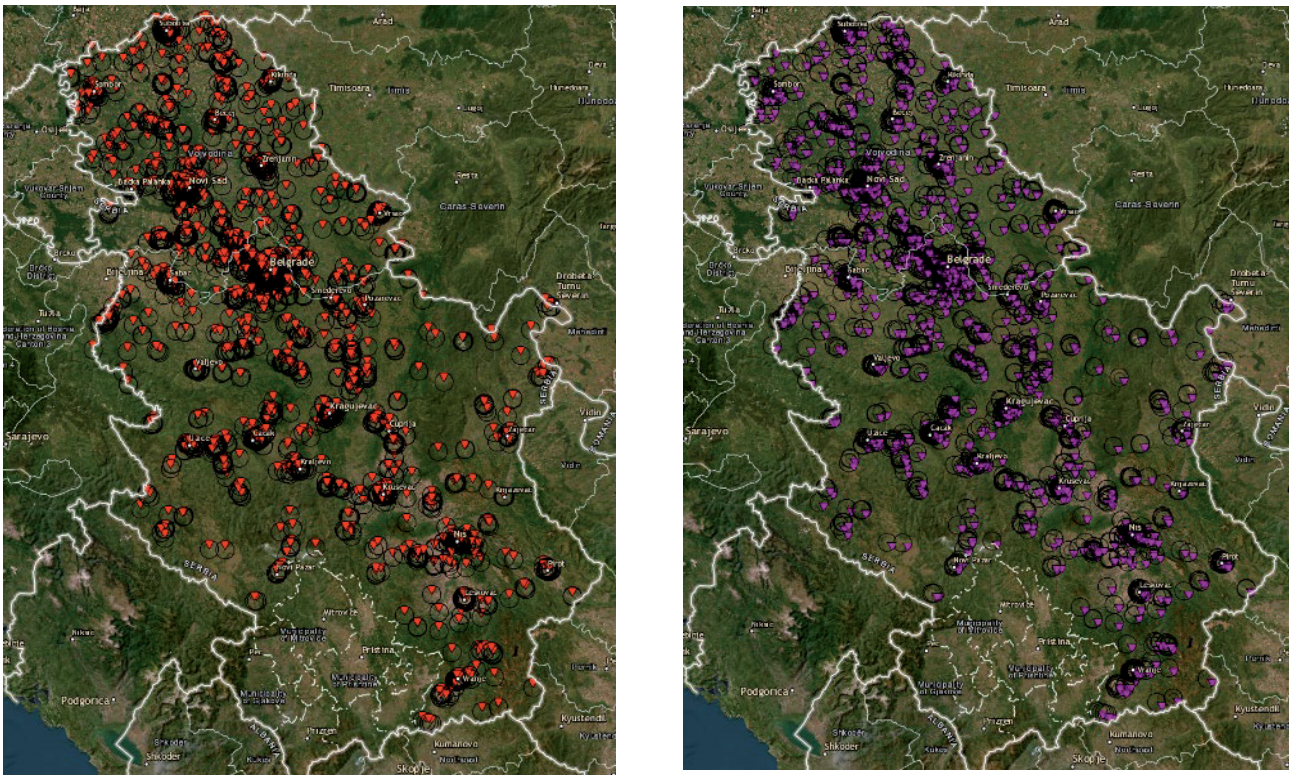


Fig. 1. Waste generated (right) and waste treatment (left) in Serbia [2].

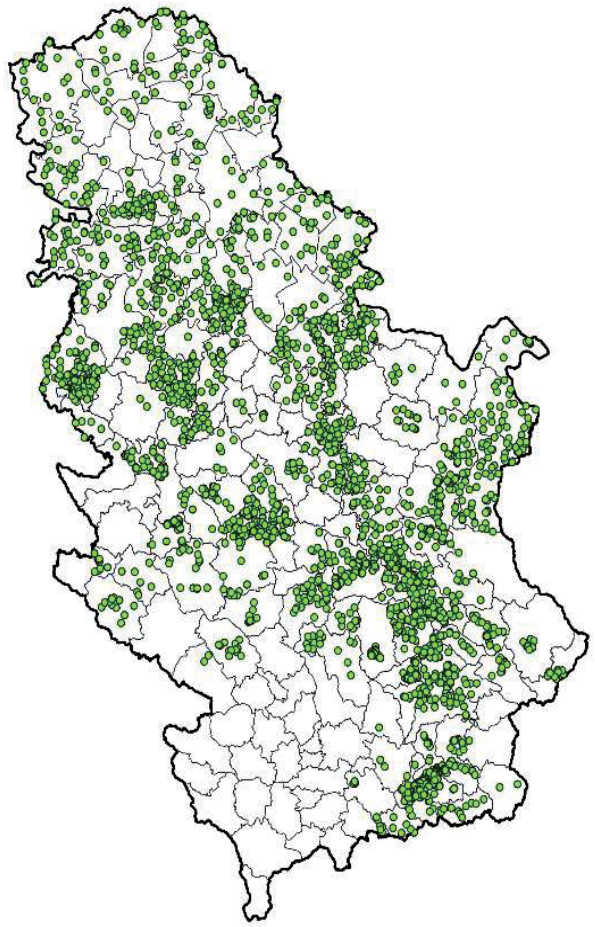

Fig. 2. Illegal dumpsites in Serbia [1].

than 100 m from settlements or 50 m from rivers [1]. The consequences of waste disposal at non-sanitary landfills include threats to flora and fauna, leachate runoff, soil contamination, and emissions of nitrogen and sulfur oxides, dust, heavy metals, and methane. A slight downward trend in the number of non-sanitary landfills has been observed, and the construction of 26 technically adequate sanitary landfills is expected [1].

Another significant issue is the presence of illegal dumpsites (Fig. 2), which cover an area of 8,145.361 m² and contain 2,094.291 t of waste [1, 2], according to the latest measurements from 2024. A major problem is that waste is repeatedly disposed of at the same locations, even after the sites have been cleaned. Sites near Belgrade, Vranje, and Požarevac have been cleaned more than 100 times, while the illegal dumpsite near Leskovac has been cleaned 174 times [1]. Illegal dumpsites are most commonly located in rural areas and alongside roads.

The Balanced Scorecard (BSC) method provides a framework for planning, which serves as the first phase of waste disposal site reclamation management. The strategic perspectives of the BSC method [3, 4], based on a clear representation of the current situation and the implementation of efficient, innovative, and progressive solutions [5, 6], are of great significance for addressing these complex problems. Municipal waste can be viewed as an energy resource [7]; therefore, such possibilities must be considered within the waste disposal process. Waste in the form of construction materials can also be utilized in the production of

concrete aggregate; in this sense, it represents an economically viable secondary raw material [8] essential to the circular economy process. The strategic direction regarding the sustainable recycling of plastic materials [9] encompasses the application of technical procedures accompanied by the control of heavy metal content and the potential presence of radioactive metals.

Network planning is a process analysis that involves describing a work diagram, which can be used to estimate and determine the path of activities that require precise control [10]. The network planning technique is suitable for further consideration in the selection of an appropriate management system [10], along with the analysis of activity durations [11] and the definition of the critical path [12]. The selection of the network planning technique was carried out based on the results of the BSC method and the proposed management strategies, an approach that has not previously been applied. Activities located on the critical path [13] should be additionally analysed during the decision-making process [14].

A large number of studies have demonstrated significant advantages of defining strategic perspectives [3-6], but not in combination with determining the duration of work activity planning using the CPM method. The selection of management performance indicators using the BSC method represents a suitable tool [7, 8] for solving complex problems, particularly when management processes are conducted in accordance with sustainable development guidelines. The application of the hybrid BSC-CPM model creates a basis for implementation by municipal system management, which has not previously been considered within research studies. In this way, the problem of waste disposal can also be addressed at the national level, for which there is a significant need in the Republic of Serbia.

The objective of applying the hybrid model in the waste disposal management process is to increase organizational productivity through the implementation of strategic management principles, reduce operating costs, and shorten the duration of the management project. In addition to the main objective, the proposed model is of great importance for improving environmental protection systems and preserving the quality of soil and groundwater in the vicinity of municipal waste landfills.

## Materials and Methods

Waste disposal site reclamation, as a significant environmental challenge, can be addressed incrementally and in phases, utilizing available financial resources. Current legislation mandates that operators of municipal solid waste landfills adequately monitor soil quality, remediate the consequences of waste disposal, and manage the quality of leachate and the dispersion of particulate matter.

The application of the Balanced Scorecard (BSC) method can serve as a strategic framework for planning aimed at overcoming accumulated environmental issues. Through this method, the management process is split into priority objectives, the achievement of which depends on the financial situation, public response, and the readiness of management to mitigate the degree of environmental degradation.

Municipal solid waste landfill reclamation based on the contemporary management perspectives of the BSC method can be viewed as a foundation for planning procedures for the partial, significant, or complete mitigation of the consequences of inadequate waste disposal. The ultimate goal is to establish the conditions necessary for the full implementation of legal regulations and the realization of sustainable development principles. Furthermore, the recovery of exploitable materials from waste aligns with the core principles of the circular economy. A systems approach to resolving illegal dumpsite reclamation issues involves a partial assessment of the actual situation from various perspectives, as well as multi-criteria decision-making that leads toward a permanent resolution of these issues.

The definition of clear and realistic reclamation goals within the environmental protection management system model is based on the application of BSC strategic perspectives. The proposed strategies primarily encompass corrective protection measures, as they address scenarios where the degradation of primary environmental elements has already occurred. Furthermore, the proposal of preventive measures is of vital importance for aligning business operations with contemporary waste disposal solutions. The process of defining priority and long-term objectives for the protection of soil, water, and air will be conducted in accordance with available financial capacities. It is important to propose solutions that are realistically achievable and contribute to the long-term modernization of waste disposal processes. The proposed model for environmental protection and waste disposal site reclamation management is based on the guidelines of modern strategic management perspectives. The application of new management perspectives, as well as the integration of new proposals into existing ones, establishes a foundation for developing innovative solutions and adhering to the principles of sustainable development. The BSC method involves the improvement of management processes through the application of:

- Environmental and social aspects as integral components of existing strategic management perspectives;
- Environmental and social aspects as standalone strategic management perspectives;
- Environmental and social aspects as derived strategic perspectives integrated into the core strategic management perspectives;
- Integrated Balanced Scorecard strategies tailored to specific management conditions.

The application of the aforementioned methods for integrating key environmental aspects into planning analyses establishes a foundation for identifying and gradually rectifying oversights in the implementation of adopted protection measures. An assessment of the current situation reveals significant environmental issues that require the use of modern reclamation procedures.

From an environmental protection standpoint, it is crucial that environmental aspects become an integral part of strategic management perspectives; however, social aspects must not be overlooked. When creating a management framework, one may begin with the premise that relevant environmental aspects and recommended protection measures are addressed within the realization of existing strategic perspectives. This approach creates the necessary conditions to simultaneously anticipate the application of sustainable development principles and compliance with legal requirements.

The environmental management model can also be more complex. In such cases, at least one socio-environmental perspective should be developed, adhering to the fundamental principles of sustainable development. The significance of this proposal lies in the fact that it establishes a link between strategic perspectives.

Socio-environmental perspectives can also be viewed as a proposal to implement management plans through market-oriented activities. It is necessary for the proposed strategic perspectives to simultaneously exert positive effects on the mitigation of environmental issues. The expected outcomes of such implementation are based on recovering the utility value of the waste that was deposited at the waste disposal site, while also implementing prescribed protection measures.

A management model based on the inclusion of environmental and social aspects within the strategic perspectives of municipal utility companies represents a significant shift from conventional management methods. The expected results of such plans include a clear observation of progress in achieving adopted environmental goals and policies. The financial investment required for this proposal is lower than that of more demanding solutions, making the proposal acceptable to management representatives. In this scenario, sustainable development principles are minimally observed, with a partial realization of the sustainable management concept.

This proposal implies that financial resources are directed toward monitoring biological system responses and erosion control, alongside internal air quality monitoring and training for timely response in cases of extreme precipitation. Stakeholder concerns can be mitigated by ensuring the transparency of documentation related to the state of the environment. A systematic overview of this approach is presented in the first part of Table 1.

A management proposal based on standalone socio-environmental perspectives implies a more significant commitment to sustainable development principles and the application of sustainable management. The expected results include more comprehensive illegal dumpsite reclamation and the improvement of environmental quality. This establishes a basis for reducing the number of grievances and fostering more ethical relationships with stakeholders. In this case, the management model is based on internal soil monitoring, with regular testing for heavy metals and polycyclic aromatic hydrocarbons (PAH) in arable land, pastures, and crops. The value of the proposal is further evidenced by a readiness to disseminate information regarding the state of the environment to stakeholders and owners of agricultural land in the vicinity of the waste disposal sites. Detailed solutions are presented in the second part of Table 1.

Special market-oriented perspectives may include industrial waste reprocessing to secure additional financial benefits from the separated waste material. Financial gains should be directed toward the remediation of waste disposal sites within factories and the reduction of soil, water, and air quality degradation. Planned activities should also include worker training for the implementation of procedures to recover the utility value of waste material that can be used as a secondary material. A detailed description of the proposed solution, based on securing additional quantities of a non-renewable resource that can be utilized even with lower usable potential, is presented in the third part of Table 1. Based on the first section of Table 1, it can be concluded that the financial investment required for the implementation of protection measures is higher compared to traditional management approaches. However, this investment is not excessive; it corresponds to the initial phase of necessary changes mandated by current environmental legislation. This proposal is significant for enhancing the corporate reputation and competitiveness of a company, particularly regarding cooperation with foreign companies. An analysis of the socio-environmental aspects viewed as standalone perspectives, as shown in Table 1, leads to the conclusion that the presence of heavy metals in the soil is a significant issue.

There is a need to initiate the proposed solutions to reduce the contamination of agricultural crops. The presentation of planned activities within the realization of a special, market-oriented strategic perspective achieves the highest level of sustainability. The process of gradual alignment toward a sustainable management concept, shown in the third section of Table 1, establishes a basis for determining potential secondary materials within the waste and demonstrates to stakeholders that the company adheres to the principles of sustainable development.

## Environmental and Social Aspects as Strategic Environmental Management Perspectives

A strategic perspective based on socio-environmental aspects can be viewed as a specific

Table 1. Proposal for integrating socio-environmental aspects into strategic environmental protection management perspectives (SP – Strategic Perspectives, F – Financial, C – Customer/Stakeholder, IBP – Internal Business Processes, L&G – Learning and Growth, ENV – Environmental, SOC – Social, SEC – Socio-Environmental).

| Characteristics and Evaluation of the Proposal for Integrating Socio-Environmental Aspects | | SP | Proposal for Integrating Socio-Environmental Aspects (SEA) into Strategic Perspectives |
|---|---|---|---|
| SEA as an Integral Part of SP | Expected Results:<br>Proposal aligns with Environmental Protection (EP) policy.<br>Encourages respect for stakeholders and the public.<br>-Minimal financial investment relative to actual needs and ecological problems.<br>Sustainable Management Concept: Partial<br>Sustainable Development Principles:<br>Lower level of implementation planned | F | Financial investment in monitoring biological system responses and erosion control |
| | | C | Provision of transparent documentation for the local community and the interested public |
| | | IBP | Internal monitoring system for particulate matter dispersion in the direction of dominant winds |
| | | L&G | Training for timely response to extreme precipitation and warnings regarding waste disposal site leachate caused by atmospheric precipitation |
| SEA as a Standalone SP | Expected Results:<br>-Improvement of the EP management system in the processes of industrial waste separation and waste disposal site reclamation<br>-A significant step toward establishing better stakeholder relations to reduce grievances<br>Sustainable Management Concept: Significant<br>Sustainable Development Principles:<br>Higher level of implementation planned | E | Internal soil monitoring and control of heavy metal presence in agricultural land |
| | | S | Warning agricultural landowners in the event of increased heavy metal concentrations in arable land |
| | | SEC | Internal soil monitoring, tracking changes in heavy metal concentration levels, and potential public warning notification |
| SEA as a Derived SP | Expected Results:<br>-Implementation of EP measures alongside a profit-oriented strategy<br>-Generation of additional profit to be directed toward resolving ecological problems<br>-Provision of additional non-renewable resources usable even with lower usable potential<br>-Recovery of the utility value of industrial waste following an initial investment<br>Sustainable Management Concept: Most significant<br>Sustainable Development Principles:<br>Highest level of implementation planned | F | Industrial waste reprocessing aimed at securing financial benefits and more efficient utilization of non-renewable natural resources |
| | | K | Familiarizing users/stakeholders with plans to implement modern or improved secondary material processing methods<br>Opening possibilities for mitigating negative environmental impacts |
| | | IP | Internal processes for determining potential quantities of secondary materials within waste material |
| | | L&G | Training workers to perform secondary materials reprocessing procedures |

management perspective considered within the framework of existing strategic perspectives. Introducing a dedicated perspective is a complex procedure, as a derived perspective must be market-oriented while simultaneously being linked to all other strategic perspectives. It is necessary to adapt integrated management strategies to the specific state of the waste disposal site and the conditions under which excavated soil layers are disposed of. Within the situational assessment, the following should be considered [15]: the implementation of protection measures, compliance with prescribed procedures and relevant laws, an innovative approach to problem-solving, adherence to ethical principles, and the application of the sustainable development concept.

The integration of sustainable development principles into the BSC method [15] yields a more complex methodology known as the Sustainability Balanced Scorecard (SBSC). The feasibility of integrating sustainability elements into the BSC framework depends on the type of strategy selected and the results of the environmental impact analysis. The SBSC method is based on the application of clear, efficient, innovative, and progressive strategies [4-6]. Table 2 shows the significance of management through the implementation of these strategies, including their practical application.

Table 2 provides a comparative overview of the implementation of clear, efficient, innovative, and progressive strategies, featuring specific examples for enhancing soil, water, and air quality. The structural differences between these strategies are defined by their distinct objectives and results of their application. The characteristic principles of the Clear Strategy (CS), defined for waste disposal site reclamation management, involve strict adherence to prescribed environmental protection requirements. In this context, the strategy proposes the implementation of protection measures, the mitigation of negative stakeholder perceptions, and the organization of monitoring systems; essentially, activities are selected to demonstrate visible, positive changes in addressing environmental issues.

Table 2. Comparative overview of Clear (CS), Efficient (ES), Innovative (IS), and Progressive (PS) SBSC strategies for addressing air, water, and soil pollution (OA – Objective of Application, PA – Proposal for Application, RA – Results of Application).

| | | |
|---|---|---|
| Clear Strategy (CS) | OA | Operation of the environmental protection system while considering stakeholder perspectives, adhering to protection measures, and addressing public grievances |
| | PA | Waste disposal site reclamation and organization of monitoring systems for drainage water and soil |
| | RA | Presentation of positive changes within the environmental protection system |
| Efficient Strategy (ES) | OA | Direction of a larger portion of financial investment toward preventive protection measures to reduce the necessity for corrective actions through more precise implementation |
| | PA | Utilization of underground cavities and natural soil depressions |
| | RP | Increased investment in reclamation process improvement, leading to improved environmental quality and a reduced need for corrective measures |
| Innovative Strategy (IS) | OA | Implementation of market-oriented preventive environmental protection measures |
| | PA | Application of procedures for the reuse of natural resources from agricultural waste, in keeping with circular economy principles |
| | RA | Development of an environmental management strategy that integrates recycling and the utilization of agricultural waste as a secondary raw material |
| Progressive Strategy (PS) | OA | Planning of a reclamation strategy based on industrial waste reprocessing, remediation of negative impacts due to waste materials, and elimination of causes of potential natural or anthropogenic emergencies |
| | PA | Implementation of reclamation as well as protection measures to mitigate risks of fire, drought, floods, drainage spills, landslides, and earthquakes |
| | RA | Development of a reclamation management strategy focused on securing funds for remediating the consequences of inadequate industrial waste disposal |
| Soil Quality Improvement | CS | Establishment of green buffer zones at dump perimeters<br>Application of prescribed soil protection measures |
| | ES | Preservation of the humus layer for covering reclaimed sites<br>Disposal of waste in underground cavities and natural soil depressions |
| | IS | Reuse of industrial waste and extraction of remaining secondary materials from municipal waste |
| | PS | Land reclamation applying climate change adaptation principles<br>Waste disposal site remediation based on phytostabilization |
| Water Quality Improvement | CS | Planting of species that accumulate heavy metals<br>Application of prescribed surface and groundwater protection measures |
| | ES | Monitoring of water passing through municipal waste landfill dam structures |
| | IS | Treatment of drainage water and waste disposal site dewatering in cases of extreme precipitation |
| | PS | Purification of drainage water for terrain stabilization and reuse for dust suppression during dry periods or in cases of fire |
| Air Quality Improvement | CS | Establishment of wide functional green buffer zones<br>Application of prescribed air quality protection measures |
| | ES | Backfilling of the waste disposal site with soil and misting for dust suppression |
| | IS | Purification of combustion products when caloric agricultural waste components in the form of biomass are burned in specialized boilers |
| | PS | Extraction of waste elements with high potential for spontaneous combustion |

The Efficient Strategy (ES), as a component of the proposed management model, provides guidelines focused on increased investment in preventive measures. The goal is to redirect funds typically reserved for corrective actions toward more advanced waste disposal techniques, thus reducing the encroachment on agricultural land.

The Innovative Strategy (IS) involves the application of market-oriented protection measures, emphasizing the significance of circular economy principles [16]. The results of this approach are based on utilizing a portion of the agricultural waste as a secondary raw material. The protection of the environment from degradation requires a multi-dimensional approach to this problem [17].

The Progressive Strategy (PS) represents the highest level of positive transformation in the management process. Its plan includes the implementation of modern

industrial waste reprocessing procedures and preventive measures to reduce the risk of emergencies. The problem with implementing this strategy is the lack of immediate financial resources; therefore, it is necessary to transition through less demanding strategic solutions to reach the advanced recycling procedures.

The second part of Table 2 presents the practical application of these strategies through direct proposals for soil, water, and air quality improvement, as well as for the application of the CPM method. The defined strategic perspective guidelines are used as a basis for defining the work activities of the management process within network planning. Soil quality preservation is based on initiatives that begin with prescribed measures, such as establishing green buffer zones and preserving the humus layer intended for the waste disposal site (CS). This is followed by proper disposal of waste in areas with degraded land in natural depressions or underground cavities (ES), the extraction of useful components from the waste (IS), and finally, soil remediation based on phytostabilization (PS).

Water quality enhancement is planned through the implementation of protection measures and the planting of hyperaccumulating species (CS), the organization of water monitoring systems (ES), the treatment of drainage water and dewatering during periods of extreme precipitation (IS), and the purification and reuse of drainage water (PS).

Air quality depends on the dispersion of particulate matter during periods of increased airflow and the risk of potential fires. Air quality is improved by establishing wide, functional green buffer zones and air protection measures (CS), backfilling municipal waste landfills with soil alongside regular misting (ES), and purifying the combustion products from biomass of agricultural crops and isolating industrial waste elements with a high potential for spontaneous combustion (PS).

CPM, or the critical path method, is a method that can be used to plan and manage a project using a time-activity flowchart diagram when the relationships between its resources have been determined with certainty. The critical path in the CPM method can be determined based on the total duration of the project. A critical path is a sequence of critical activities that determines the timeframe for project completion [11].

Advanced calculation is a method used to determine the critical path, starting from the first node in the project activity network diagram. The calculation model of the CPM method is the Forward Pass Calculation [11]:

$$ES = max(EF\ previously) \quad (1)$$

$$EF = ES + duration \quad (2)$$

where *ES* is the earliest start time (Early Start) and *EF* is the earliest finish time (Early Finish).

Countdown is a method that can be used to define the critical path of the endpoint deep Diagram Activity pipeline project - Backward Pass [11]:

$$LS = LF\text{-}duration \quad (3)$$

$$EF = min(LS\ next\ activity) \quad (4)$$

where *LS* is the latest start time (Late Start), and *LF* is the latest finish time (Late Finish).

Work activities are defined based on the guidelines of strategic perspectives. Their duration is determined within the network plan. The mentioned work activities are part of the planned obligations. They serve as a starting point for the application of network planning techniques.

## Results and Discussion

Modeling the environmental protection management system in relation to the waste disposal process provides an opportunity to identify and adequately address one of the most significant causes of air, water, and soil pollution. Observing the implementation of preventive protection measures indicates that more substantial financial resources must be directed toward overcoming these challenges. The lack of sustainable technical solutions should be addressed gradually, establishing a foundation for the further hiring of professional personnel who could more efficiently manage planned financial capacities and the realization of adopted environmental policy objectives. The proposed management model, based on clear, efficient, innovative, and progressive strategic perspectives, is ambitious but achievable through the application of the CPM method. It requires a commitment to improving environmental quality, conserving available natural resources, implementing more adequate waste disposal procedures, and complying with legal regulatory guidelines. Innovative solutions necessitate a multidisciplinary approach to the decision-making process, as can also be observed from the proposed list of activities.

Table 3 presents the characteristics and proposed application methods for the core strategic perspectives, based on the implementation of methods of varying levels of complexity. The implementation of the Clear Strategy (CS) within the environmental management process of a mining and energy complex can be achieved using either the partial method or the shared-service method. The partial method involves the integration of one or more environmental aspects into one of the four primary perspectives [10]. In this study, the partial method is based on greater financial investment in protection measures and proposals for internal processes regarding the greening of waste disposal sites that have no capacity for further waste disposal (Table 3). The shared-service method is based on the integration of two or more strategic perspectives simultaneously. It is viewed in terms of three proposals: Financing of internal monitoring systems (F-IBP); Financing of remediation training (F-L&G); and Financing of internal training for climate change adaptation (IBP-L&G).

The Efficient Strategy (ES), represented by the partial method (Table 3), is presented through the proposal for financial investment in waste, as well as internal procedures based on waste disposal in degraded land, natural depressions, or pits. The Innovative Strategy (IS) is based on the combustion of biomass and agricultural crop residues, utilizing either the partial or the total method. The total method encompasses financial gains

Table 3. Potential opportunities for implementing proposed strategies based on Partial (PA), Shared-Service (SS), Total (TO), Expanded (EX), and Transversal (TR) methods.

| Characteristics of proposed strategies and implementation opportunities | | | |
|---|---|---|---|
| Clear Strategy | PA | F | Higher level of financial investment in the implementation of protection measures |
| | | IBP | Improving internal processes for monitoring vegetation cover, green buffer zones, and functional protective greenery between the municipal solid waste landfill and surrounding settlements |
| | SS | F, IBP | Financial investment in the implementation of internal monitoring systems for drainage water |
| | | F, L&G | Funding additional training programmes for selecting adequate plant species for remediation processes |
| | | IBP, L&G | Internal training for the implementation of climate change adaptation processes |
| Efficient Strategy | PA | F | Financial investments in procedures for using waste as a secondary raw material |
| | | IBP | Internal waste disposal process on degraded land while preventing contamination of deep groundwater levels |
| | | IBP | Utilizing natural soil depressions for waste disposal and applying impermeable lining to the internal surface of the depression; Accumulating the waste in specially excavated pits and stripping and preserving the humus layer for covering waste upon completion of disposal; Construction of ring embankments around the municipal waste landfills with adequate water pumping systems |
| | | IBP | Planting species suitable for remediation that are simultaneously climate-resilient and adapted to specific municipal waste landfill conditions<br>Implementation of agromeliorative measures and monitoring the status of plant species |
| Innovative Strategy | PA | IBP | Internal process of burning biomass in specialized boilers to generate thermal energy |
| | TO | F | Financial gain from selling waste as a secondary raw material |
| | | C | Utilization as a low-cost secondary raw material to replace cement, sand, or gravel in concrete and cement production |
| | | IBP | Internal processes for maintaining and constructing access roads to the waste disposal sites for fire vehicle access, using construction waste as embankment material or asphalt base; Internal processes for planting fire-protection belts |
| | | L&G | Researching modern processes for recycling |
| Progressive Strategy | TO | F | Financial investment in the development of industrial waste reprocessing<br>Construction, maintenance, and expansion of access roads to the waste disposal sites planned for fire vehicle access |
| | | C | Creating conditions to reduce fire risk and the potential for spontaneous combustion of methane located beneath the municipal waste |
| | | IBP | Internal processes for municipal solid waste landfill reclamation and remediation based on phytostabilization |
| | | L&G | Learning and growth related to modern municipal solid waste landfill remediation approaches: bituminous geomembranes, dewatering and water reuse |
| | EX | ESA | Construction of solar and wind power plants on degraded lands where landfill reclamation has been completed with low reclamation potential that are unsuitable for agriculture |
| | TP | F | Financial investments to utilize industrial waste as a secondary raw material and degraded land for alternative energy, while generating profit |
| | | C | Realizing principles of sustainable energy development and meeting stakeholder requirements |
| | | IBP | Internal processes for restoring the utility value of degraded areas through the application of solar and wind energy at suitable locations |
| | | L&G | Training personnel for climate change adaptation and developing management processes toward sustainable modern solutions<br>Preventing ecological disasters resulting from the runoff of municipal solid waste landfill drainage water |

from the use of biomass as a secondary raw material, the addition of construction waste to concrete for road construction purposes, or participation in access road construction processes for the waste disposal site. The Progressive Strategy (PS) is planned through three distinct methods: total, expanded, and transversal. The total method includes financial investment in industrial waste reprocessing (F), fire risk mitigation (C), remediation proposals (IBP), and learning and growth (L&G) related to modern reclamation processes. The expanded method is based on the proposal to utilize reclaimed landfill area for alternative energy sources. The transversal method is based on the application of land utility restoration processes [11] and the specialized training of personnel for climate adaptation.

An analysis of the potential opportunities for implementing clear, efficient, innovative, and progressive strategic management perspectives, as presented in Table 3, clearly identifies the key elements for developing a waste disposal site reclamation Hybrid BSC-CPM management model. The framework for this model is built upon activities designated for implementation through the proposed strategies:

– Partial Strategy (PA),
– Shared-Service Strategy (SS),
– Total Strategy (TO),
– Expanded Strategy (EX), and
– Transversal Strategy (TR).

The objective of this type of Hybrid BSC-CPM management model is to ensure financial gain while reducing the financial costs associated with remediating the negative consequences.

The parallel implementation of new and existing strategic perspectives is often difficult to adopt during the organizational phase, as it may be poorly received by management.

While the profit orientation of the proposal is significant, the level of initial investment must also be considered.

From a sustainability standpoint, the proposal is of great importance; therefore, it is necessary to address these issues at the national level with government support and guarantees.

A systematic assessment of the operational challenges in the waste disposal process, based on the consideration of all relevant environmental protection aspects, is feasible.

The proposed model offers multiple options for adaptation, allowing for alignment with financial capacities, available technical potential, and professional personnel:

– The Clear Strategy (CS), grounded in the practical application of adopted environmental goals and protection measures, can contribute to the proper functioning of the waste disposal process;
– A significant challenge that still remains is the inconsistent application of legal regulations and the tendency to justify lapses in preventive measure implementation by citing a lack of financial resources;
– The model includes proposals for the co-firing of rejected waste from agricultural production with biomass; this approach generates financial gain while reducing waste;
– Transforming the costs associated with corrective measures into strategic investments for modernizing disposal processes represents a critical step from the utilization of industrial waste as a secondary raw material toward full adherence to sustainable development principles.

Fig. 3 illustrates the environmental protection management system model associated with waste utilization and management processes.

The BSC model for the improvement of waste utilization and management processes shown in Fig. 3 provides a framework for assessing actual conditions within the utility system. A systematic assessment of environmental quality and the consequences of inadequate waste management indicates that problems should be addressed through partial analysis and that more efficient and progressive solutions are to be expected. The criteria used to determine the relationships between the strategic perspectives designated as F-IBP, F-L&G, and IBP-L&G are based on the principles of applying the basic form of integrating socio-environmental aspects into strategic environmental protection management perspectives. The first criterion refers to defining the need for financial investments, while the second is based on the integration of available capacities and internal processes. The implementation of monitoring systems for drainage water and training programmes for selecting adequate plant species for remediation processes requires additional financial investments. Within the framework of the Clear Strategy, Internal Business Processes are proposed as significant objectives to be achieved through financial investments (F-IBP) and the application of Learning and Growth processes (IBP-L&G).

Based on the results of the BSC method, a selection of key work activities was made. These activities can contribute to solving the problem and need to become part of the management plan. Fig. 4 shows the work activities as part of the network plan. Fig. 5 shows the network plan, with the critical path.

Based on Fig. 5, it can be seen that activities 1-9 and activity 19 are on the critical path (Environmental Protection Management System Model related to the waste disposal process). Special attention should be paid to critical activities during implementation. If they are not completed on time, the time required to implement the network plan may be extended.

Fig. 6 presents the key activities, which are at the beginning of lower-level network paths 6 (Investment in complex waste disposal processes) and 17 (Waste disposal site reclamation model in accordance with the principles of sustainable development). After activity 6, activities 7 (Regular monitoring of the waste disposal site condition and the presence of pollutants in drainage water), 10 (Waste disposal on degraded land, natural

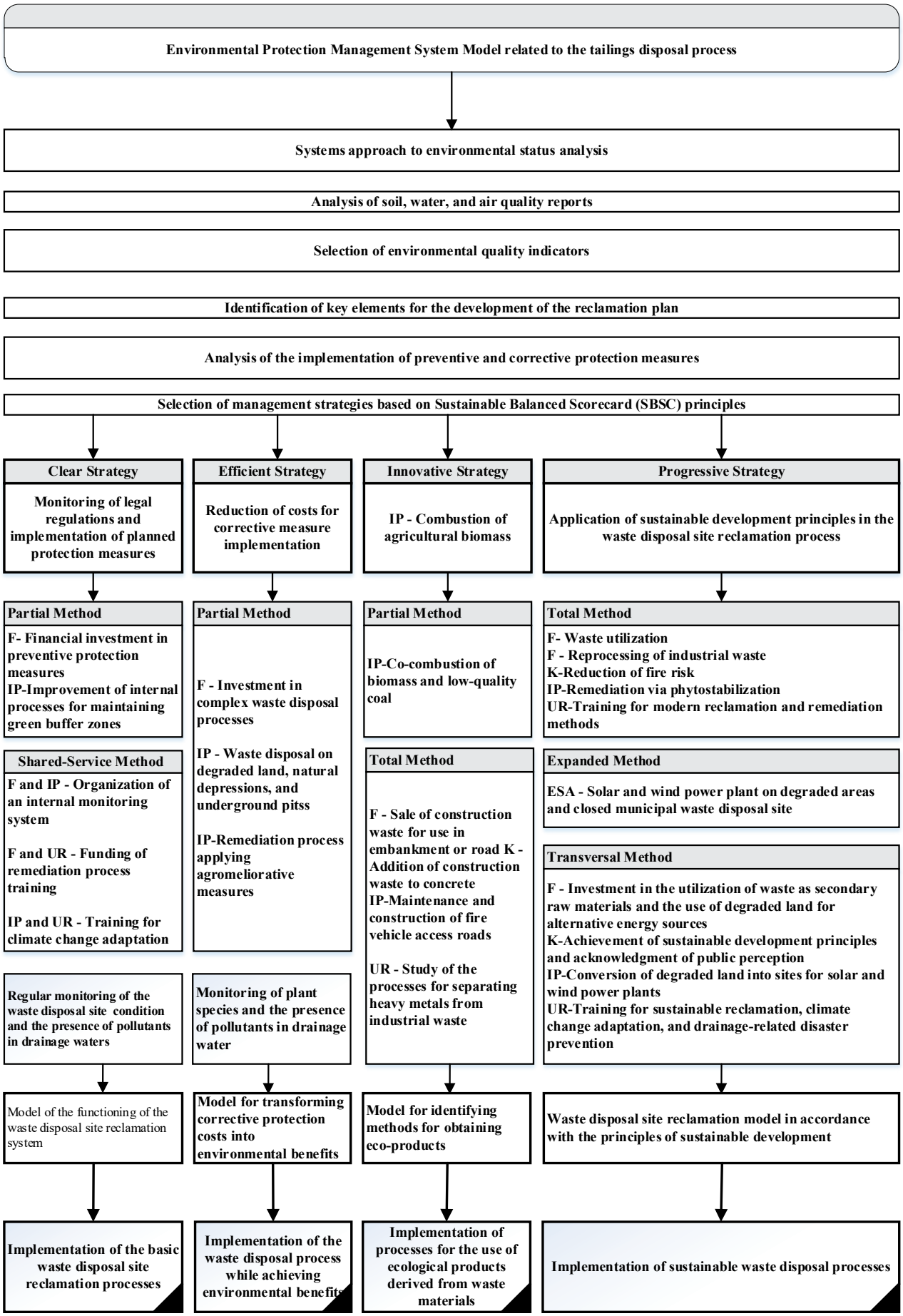


Fig. 3. Environmental protection system model associated with waste utilization and management processes.

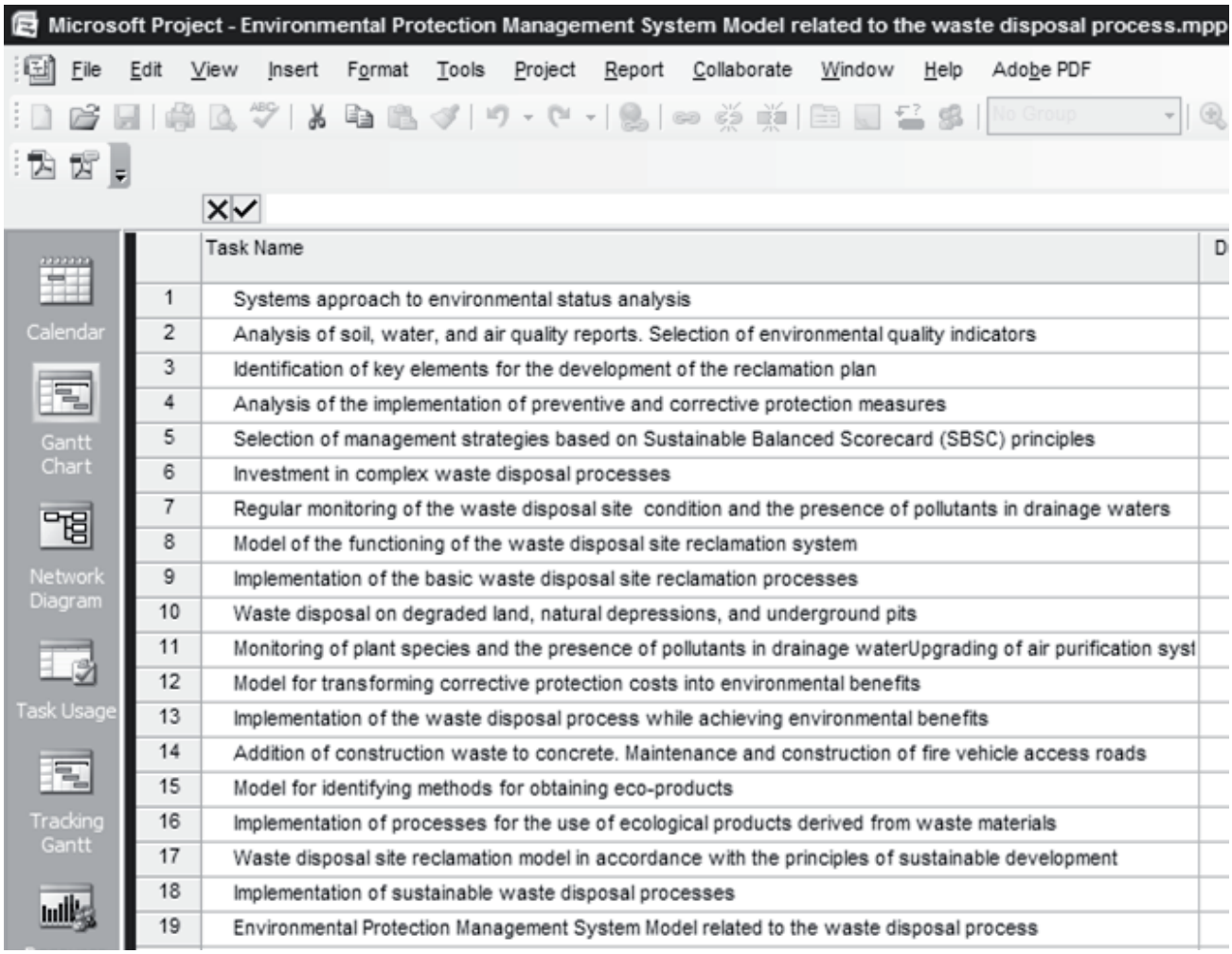


Fig. 4. Work activities defined within the network planning process.

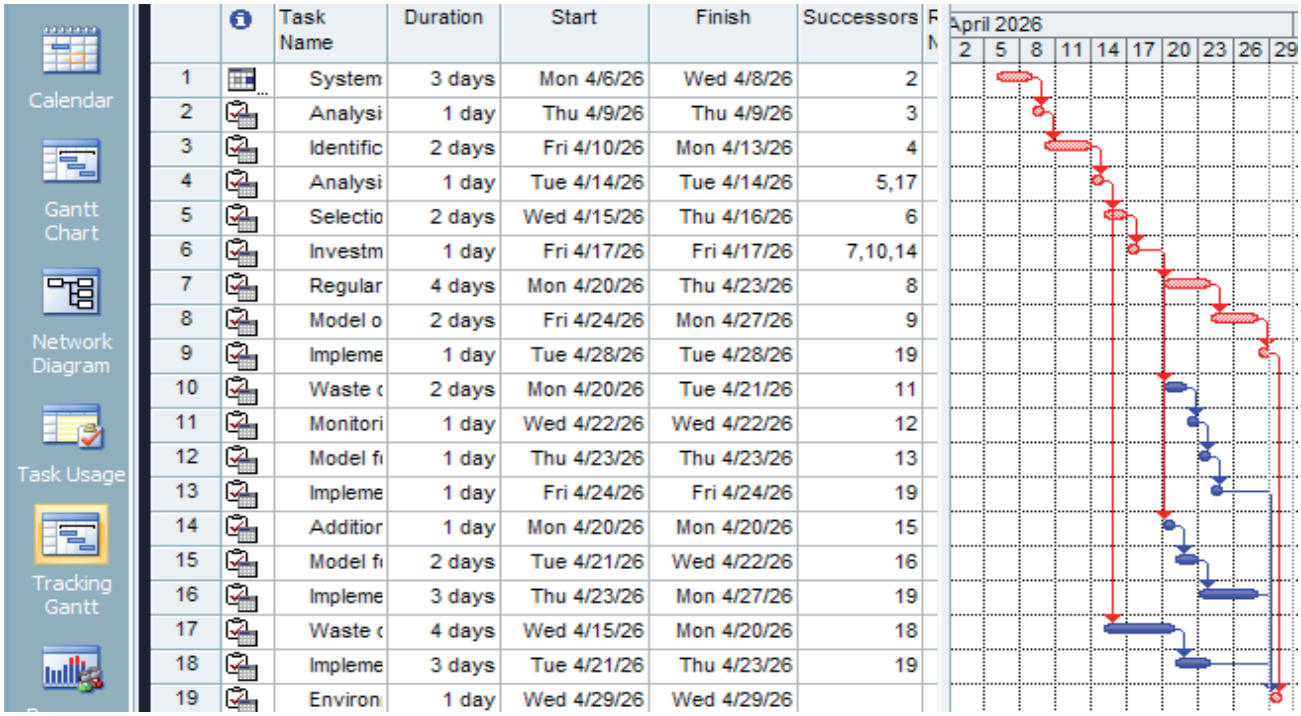


Fig. 5. The duration of work activities and the network plan with the critical path.

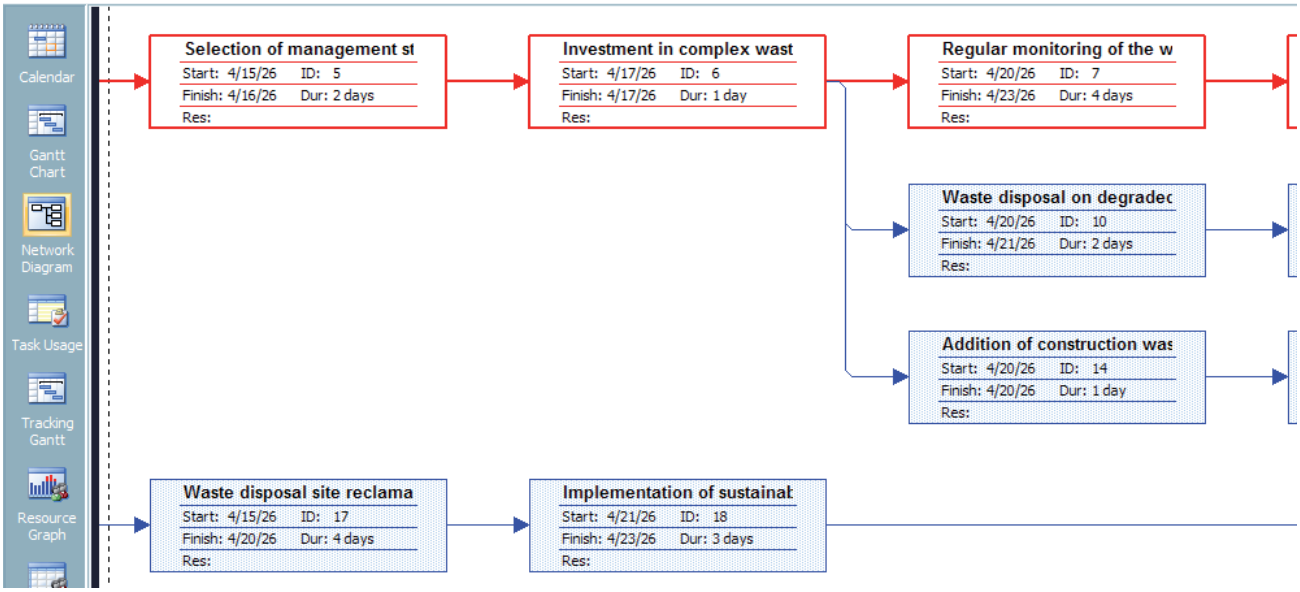


Fig. 6. Key work activities.

depressions, and underground pits), and 14 (Addition of construction waste to concrete) are implemented.

The network plan can be realized in less than 30 days. Solving the problem of waste disposal should be performed at the national level. The presented network plan represents solutions that are in line with sustainable development. The application of this plan, based on the BSC method, has a realistic basis for progress in the management process.

Contemporary research indicates that the resolution of such complex problems can be achieved through the analysis of strategic perspectives [18] and complex management processes. The BSC is recognized as an effective tool for measuring strategic performance; however, it does not necessarily provide clear feedback regarding causality and the interrelationships among subsystems associated with performance indicators [19], which may represent a significant limitation. This challenge can be addressed through the integration of BSC results into management structures by means of strategic management [20], whereby the mission and strategy for achieving organizational goals are considered simultaneously. The Critical Path Method (CPM) was selected as the primary tool for supporting strategy implementation, as it represents the foundational basis for planning organizational, technical, and economic measures. It was utilized in this paper because it relies on a straightforward analysis of time and execution deadlines for individual phases. This approach ensures easier application and greater acceptability by decision-makers compared to the PERT method. Furthermore, this method provides a realistic basis for analyzing the structure of the land reclamation process and clearly displays the execution sequence of planned work activities. The main advantage of this method is its applicability to solving such a demanding problem, which depends on a large number of factors and does not provide a basis for applying methods based on rapid, efficient reactions (Agile) or strict phase definitions within a stable environment (Waterfall).

However, the direct application of the BSC and CPM methods in the field of waste disposal and utilization has not yet been implemented. These methods may be applied through the parallel analysis of financial conditions, public attitudes, internal processes, and development perspectives [21], as part of a broader process of strategic alignment. Existing studies also emphasize the importance of human capital [22] as a resource capable of bridging the gap between the formulation of strategic solutions and their practical implementation, which this study seeks to accomplish.

The combined application of the BSC and CPM methods represents a hybrid model that contributes to linking strategic perspectives with organizational management performance. In this way, the first part of the study identifies key operational activities within the waste disposal process (e.g., internal soil monitoring and control of heavy metal presence in agricultural land), while the second part identifies activities that may affect project implementation within the planned timeframe. Accordingly, the defined strategic perspectives (internal monitoring system for particulate matter dispersion in the direction of dominant winds; internal soil monitoring, tracking changes in heavy metal concentration levels, and potential public warning notification; internal processes for determining potential quantities of secondary materials within waste streams) are directly aligned with strategic objectives.

The characteristics of the Proposal for Integrating Socio-Environmental Aspects influence the required financial investments for addressing waste disposal issues, depending on the level of implementation of Sustainable Development Principles:

– Lower level of implementation: Financial investments include the costs of implementing reclamation measures, internal monitoring systems for water and air, investment in biological system response monitoring, erosion control, and training for timely emergency response.
– Higher level of implementation: Significant financial investments for organizing internal soil monitoring, controlling the presence of heavy metals in agricultural land, and, if necessary, organizing the land remediation process.
– Highest level of implementation: The most significant financial investments in waste processing, internal processes for determining potential secondary material quantities, and the implementation of environmental protection measures alongside a profit-oriented strategy.

The estimated costs associated with implementing the individual stages of the proposed model depend on the objectives of the adopted environmental policy at the national level. The analysis shows that median restoration costs vary from 185 USD/ha to 3,012 USD/ha depending on the restoration measure, implying that current global land restoration commitments would cost 0.04%-0.27% of annual global GDP to implement [23].

According to the current legal regulations [24, 25], the process of developing land reclamation and remediation projects can only be performed by a licensed design organization that meets the necessary technical equipment requirements. The soil protection plan is adopted by the Government of the Republic of Serbia on the proposal of the Ministry for a period of seven years, based on the Annual Soil Protection Program. The costs of remediating the consequences of waste disposal can be estimated by professional organizations based on a detailed techno-economic analysis of soil quality and the consequences of inadequate implementation of protective measures. The financial costs of reclamation further increase if the procedures for collecting and treating drainage water, removing landfill gases via gas wells, draining stormwater, and daily covering with inert material are not adequately implemented.

## Conclusions

The proposed management model for the waste reclamation process – ranging from fundamental procedures within acceptable legal frameworks to advanced sustainable solutions – serves as a foundation for realistic decision-making. A management process based on strategic planning necessitates making decisions that are achievable within a specific timeframe. The selection of viable solutions depends on the readiness of management to implement innovative proposals and to invest in specialized training for personnel to resolve existing environmental issues. Multi-criteria decision-making (MCDM), supported by a multidisciplinary approach, may be facilitated by the proposal presented in this study. Given that different types of waste are often deposited without selection and are highly prone to spontaneous combustion, fire risk should be considered a safety concern. It is imperative that the design of access roads accounts for the passage of fire-fighting vehicles, in case of forest fires spreading to the waste disposal site or internal spontaneous combustion occurring in the waste disposal site. The application of BSC, SBSC, and CPM methods offers significant opportunities for the gradual resolution of environmental issues by providing acceptable solutions. Planning within the framework of the CPM method can be used for the first phase of management. Further research is directed towards the application of multi-criteria decision-making. The presented example is applicable at the national, local, and regional levels. Proper waste disposal is a problem that should be solved as a priority in the Republic of Serbia. The proposed model can be applied in other countries or in different regions without significant modifications, provided they are at the same level of technological development. If the resolution of public utility problems is analyzed in more developed countries, the direct implementation of the Efficient Strategy and Innovative Strategy could be considered. Modifications should be made in accordance with the analysis of the state of municipal landfills, the adopted environmental policy, and the financial status. Adjustment of the model would be based on omitting work activities related to solving problems that have not been detected in a specific utility or industrial system, or where there is no intention to address them. Regardless of that, the proposal to apply the Progressive Strategy can be implemented by countries that are at the highest level of technological development and implementation of sustainable development principles.

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## AI USage Disclosure Statement

The authors declare that no artificial intelligence (AI) tools or AI-assisted technologies were used in the conception, design, execution, analysis, interpretation, writing, editing, language revision, or preparation of this manuscript. The manuscript and all of its components represent the original intellectual work of the authors.

## Conflict of Interest

The authors declare no conflict of interest.

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