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Environmental impact assessment in civil construction. Case study: Multifunctional Medical Center in rural areas

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Abstract – **The construction sector is among the most resource-intensive human activities, generating significant pressure on natural systems. This paper presents an integrated environmental impact assessment for the construction of a small-scale Multifunctional Medical Center (P+1, 616.35 m² built area) in the rural commune of Nicorești, Galați County, Romania. A simplified Leopold matrix was applied to quantify impacts during execution and operation phases across eight environmental and social factors. The execution phase yielded a total impact score of 54/120, classified as moderate and reversible, with noise (12) and air quality (9) as dominant stressors. The operation phase generated predominantly positive effects, with social accessibility scoring 15/15. Sustainable design choices, including mineral-wool insulation, FPO/TPO membranes, triple-glazed PVC joinery, LED lighting and BMS controls, are estimated to reduce operational consumption by up to 40%. Selective waste sorting achieved over 60% recovery on site. The study confirms that rigorous EIA application from the design stage, combined with sustainable materials and post-construction monitoring, can keep environmental impacts within legal limits while delivering substantial social benefits in underserved rural areas.**

Keywords – environmental impact assessment, Leopold matrix, rural healthcare infrastructure, sustainable construction, waste management.

1. INTRODUCTION

The construction industry is widely acknowledged as one of the most environmentally invasive economic sectors, accounting for a substantial share of global resource consumption, greenhouse-gas emissions and solid-waste generation. In the European Union, buildings are responsible for approximately 40% of final energy use and 36% of energy-related CO_2 emissions, while construction and demolition waste represents around one third of all waste produced [1], [3]. In Romania, the rapid expansion of public infrastructure, particularly in rural areas, has intensified these pressures, raising the question of how environmental considerations can be effectively integrated into projects of modest scale [4], [5].

Healthcare infrastructure occupies a special place in this discussion. On the one hand, medical buildings are essential for community well-being and territorial equity; on the other hand, they involve specific functional and sanitary requirements that may amplify resource consumption during operation [12]. Rural communities such as Nicorești (Galați County) face a documented deficit in primary medical services, which justifies investment in new facilities even when environmental constraints are stringent [14].

The present paper addresses this dual challenge by analysing the environmental performance of a small Multifunctional Medical Center designed and built in Nicorești. The objective is to provide a quantitative and qualitative evaluation of the project's impact on environmental factors, using an adapted Leopold matrix [10], and to demonstrate how sustainable technical solutions can reduce that impact within the regulatory framework provided by Romanian and European environmental legislation [2], [4].

The specific aims of the study are: (i) to identify the main sources of environmental impact across project phases; (ii) to quantify the impact on air, water, soil, biodiversity, landscape and human community; (iii) to evaluate the effectiveness of waste-management and energy-efficiency measures; and (iv) to compare estimated and observed impacts in order to formulate evidence-based recommendations for similar rural projects.

From a methodological standpoint, the study contributes to the limited body of literature that applies formal EIA tools to small public-interest buildings located in rural settings, where data availability is often poor and pre-construction monitoring is rarely systematic [11]. The Leopold matrix was selected over more recent multi-criteria decision frameworks because of its robustness, ease of communication to non-specialist stakeholders and compatibility with the documentation requirements imposed by the National Environmental Protection Agency [13]. The paper is therefore of interest both to practitioners (designers, contractors, environmental consultants) and to local public authorities tasked with reviewing environmental documentation for small-scale public investments.

2. MATERIALS AND METHODS

2.1 Legal and normative framework

The assessment was carried out within the regulatory boundaries of Romanian Law 292/2018 on the environmental impact assessment of public and private projects [4], Law 195/2005 on environmental protection [5] and OUG 92/2021 on the waste regime [6]. At European level, Directive 2011/92/EU (as amended by 2014/52/EU) on EIA [2] and Directive 2008/98/EC on waste management [3] were considered. The methodological approach was further aligned with ISO 14001:2015 (environmental management systems) [8] and ISO 45001:2018 (occupational health and safety) [18]. Additional sectoral references include Government Decision 188/2002 on wastewater discharge [19] and Law 104/2011 on ambient air quality [20], which provided the threshold values used to interpret the Leopold scores.

2.2 Site characterisation

The project is located in a low hilly plain belonging to the south-eastern part of the Romanian Plain, at altitudes of 100–130 m above sea level, with terrain slopes below 5%. The local climate is temperate continental, strongly influenced by continental air masses arriving from the east and north-east, which produce wide annual temperature variations, hot dry summers and cold windy winters. Multiannual averages reported by the meteorological stations of Tecuci and Galați indicate a mean air temperature of approximately 10.2 °C, with winter minima around −15 °C and summer maxima exceeding 35 °C. Mean annual precipitation is in the range of 450–520 mm, unevenly distributed throughout the year, with a marked deficit during the summer months. Soil is of loessoid type with a moderate sensitivity to humidity, which imposes specific hydro- and thermo-protection measures. Selected geotechnical parameters used to design the foundations are summarised in Table 1 [14].

Table 1 Geotechnical parameters of the construction site

Parameter	Value / Range	Observations
Topsoil thickness	25–30 cm	Organic layer to be preserved
Marly-clay consistency (Ic)	> 1.25	High index, compact soil
Bearing capacity (q)	180–220 kPa	Suitable for shallow foundations
Groundwater level	> 4.5 m	Seasonal variations, monitoring required
Compaction coefficient	0.95–1.00	For foundation bedding layer

From a hydrographic point of view, the site is located in an area without permanent watercourses; only intermittent torrential channels are present in the wider area, but their paths lie outside the property limit and do not intersect the building footprint. As a consequence, no special flood-protection works were required. To prevent stagnation of stormwater along the access road and around the building, the design includes precast-concrete external gutters with metallic gratings, controlled discharge into the local pluvial network and slope-break manholes in the steeper segments. The water supply is connected to the public network operated by the regional utility, with an HDPE D110 main pipe and an HDPE D63 in-site distribution, while wastewater is discharged into a sealed septic tank designed for periodic emptying.

2.3 Building description

The Multifunctional Medical Center has a ground floor plus one upper level (P+1), with a total built-up area of 616.35 m² and a useful area of 500.50 m². The structural solution consists of continuous reinforced-concrete strip foundations, monolithic reinforced-concrete frames with columns and beams, perimeter masonry of autoclaved aerated concrete (AAC) blocks 25 cm thick, monolithic reinforced-concrete slabs and a timber roof structure (treated against fire and biological agents) covered with double-layer metal tiles. The functional programme integrates primary medical care on the ground floor with specialised outpatient consultation rooms on the first floor, designed in accordance with the requirements of the Ministry of Health.

The ground-floor layout includes a sheltered access lobby (windfang), a main waiting hall, a reception desk, sanitary groups for patients (including a dedicated room for persons with reduced mobility), a temporary medical-waste storage room, staff changing rooms, a staff rest area and a series of consultation rooms for general medicine, dentistry and minor procedures. The first-floor hosts specialist outpatient services such as cardiology, obstetrics-gynaecology and family medicine, together with a sterilisation room, sterile and non-sterile material storage and additional sanitary facilities. Functional circulation is organised so that patient, staff, sterile-material and medical-waste flows do not cross, in line with sanitary regulations issued by the Ministry of Health and the Public Health Directorate. Cost distribution at design stage was estimated as follows: structure 45%, architecture 30%, mechanical-electrical-plumbing systems 20% and site organisation 5% [14].

2.4 Impact assessment methodology

The methodology followed five sequential steps: (1) inventory of project activities by phase; (2) identification of affected environmental factors – air, surface water, groundwater, soil, biodiversity, landscape and human community; (3) application of an adapted Leopold matrix [10], [16]; (4) estimation of impact magnitude and duration; and (5) comparison of computed scores with the limit values prescribed by national and European legislation [4], [20].

The adapted Leopold matrix uses an intensity score from 1 to 5 multiplied by a duration coefficient (Short = 1, Medium = 2, Long = 3), producing a per-factor impact score in the range 0–15. The total score across factors is interpreted as: ≤ 30 — low impact; 31–60 — moderate impact; 61–90 — significant impact; > 90 — major impact. The same scale, with positive sign, was used to express beneficial effects in the operation phase [11].

In addition to the matrix, a complementary decision matrix was used to support the qualitative appraisal of the EIA process itself. Four criteria were considered, with weights selected to reflect the typical priorities of public investments: degree of environmental impact (weight 0.4), cost of the assessment (0.2), procedural duration (0.2) and social acceptability (0.2). Each criterion was scored from 1 to 5 based on project documentation [14] and field observations, and the weighted sum produced an overall feasibility score that was used as a sanity check on the Leopold-based results.

2.5 SWOT framing of the EIA process

To position the assessment within the broader project context, a brief SWOT analysis was carried out (Table 2).

Table 2 SWOT framing of the EIA process for the Nicorești medical center

Strengths	**Weaknesses**
Compliance with national and EU legislation; reduced environmental risk; higher social acceptability of the project	Additional design and consultancy costs; potential delays in obtaining the environmental permit and the building permit
Opportunities	**Threats**
Project optimization through sustainable solutions and green technologies; access to European funding instruments dedicated to sustainable buildings	Refusal or restrictive conditioning of the environmental permit; cost overruns due to additional mitigation measures imposed during review

The strengths and opportunities derive mainly from the regulatory leverage of the EIA procedure and from the possibility of integrating sustainable solutions early in the design. The weaknesses and threats are linked to administrative cost and to the residual risk of restrictive conditions being attached to the environmental permit, both of which can affect project feasibility for small public budgets.

3. RESULTS AND DISCUSSION

3.1 Sources of impact by project phase

Five sequential phases were considered, each generating a distinct set of pressures on the environment, as summarised in Figure 1. During the design phase, the main risks are linked to site selection (potential habitat loss) and to inefficient design that can later increase resource consumption [12], [15]. Site organisation involves vegetation clearing and top-soil removal, which may cause erosion and loss of fertile soil, as well as accidental spills of fuels or oils that contaminate soil and water [19]. The execution phase produces dust and exhaust emissions, construction waste and intensive consumption of water and energy [20]. The operation phase generates municipal-type waste, CO_2.

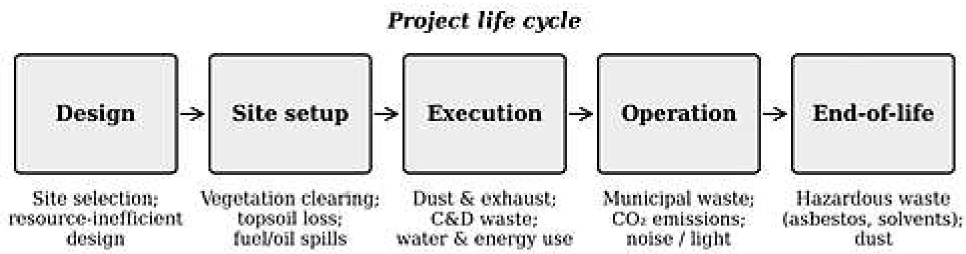

Fig. 1 Sources of environmental impact across the project life cycle

For each of these phases, the relative magnitude of pressures depends on local mitigation choices. In the present case, the limited footprint of the project (less than 0.07 hectares of disturbed area), the absence of vegetation of conservation interest and the use of local subcontractors with modern equipment kept the overall pressure on environmental factors clearly below the thresholds set by the screening criteria of Law 292/2018 [4]. Nevertheless, the cumulative effect of dust, noise and traffic disturbance in a small rural settlement was perceived as non-negligible by the local community and required dedicated mitigation, as detailed in Section 3.7.

3.2 Impact matrix – execution phase

Table 3 summarises the application of the adapted Leopold matrix to the execution phase. The aggregated score is 54/120, which corresponds to a moderate, reversible impact [10]. Noise emerges as the most affected factor (score 12), followed by air quality, landscape and human community (score 9 each). The relatively low scores for surface water (3) and groundwater (3) reflect the absence of permanent watercourses near the site and a groundwater table located safely below the excavation depth. The distribution of scores by environmental factor is illustrated in Figure 2.

Table 3 Adapted Leopold matrix – execution phase

Environmental factor	Intensity (0–5)	Duration (S/M/L)	Score (0–15)	Observations
Air quality	3	S	9	Dust controlled by watering
Soil and subsoil	2	M	6	Local contamination, manageable
Surface water	1	S	3	No nearby surface water
Groundwater	1	L	3	Water table below excavation
Noise	4	S	12	Within legal time intervals
Biodiversity	1	M	3	No protected species
Landscape	3	M	9	Temporary visual change
Human community	3	S	9	Minor perceived discomfort
Total	**-**	**-**	**54 / 120**	**Moderate impact**

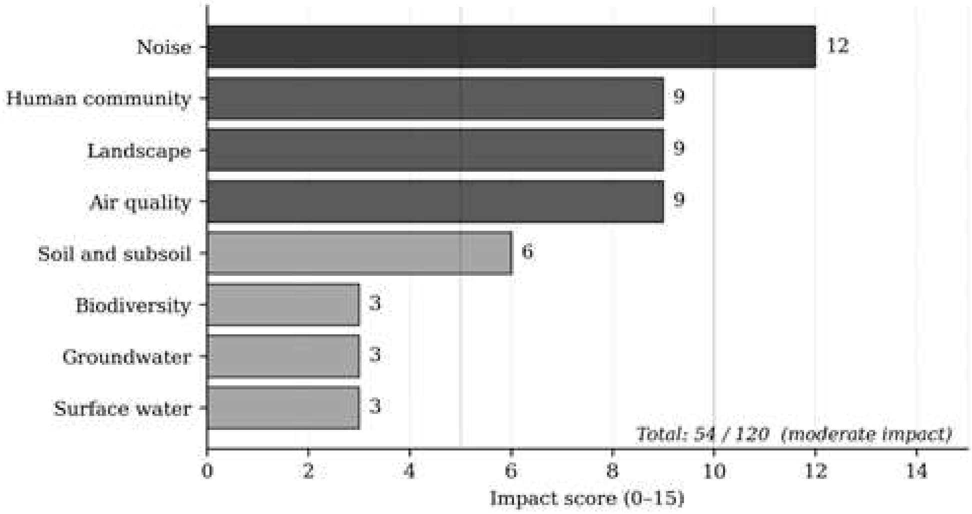

Fig. 2 Distribution of Leopold impact scores per environmental factor – execution phase

3.3 Impact matrix – operation phase

In the operation phase the sign of the impact reverses for most factors. The medical center generates positive effects on the local community by reducing the need for travel to larger urban centres for primary care, lowering associated transport emissions and improving emergency response times. Table 4 reports the dominant positive scores. The remaining negative effects (waste, energy and water consumption) are managed through standard operational procedures and were not assigned numerical penalty scores in the present analysis but should be quantified in future life-cycle assessments.

Table 4 Adapted Leopold matrix – operation phase (dominant positive effects)

Factor	Type	Intensity	Duration	Score
Air quality	Positive	2	L	+6 (fewer trips to cities)
Social accessibility	Positive	5	L	+15 (improved access to care)
Local economy	Positive	3	L	+9 (jobs and services)
Landscape	Neutral	1	L	+3 (integrated rural design)

3.4 Sustainable materials and energy-efficiency measures

A coordinated set of sustainable solutions was implemented to reduce the operational footprint of the building, in line with the principles of the Energy Performance of Buildings Directive [15] and the European Green Deal [17]. Mineral wool was selected for thermal insulation owing to its recyclable nature, non-flammability and high thermal performance. The flat-roof waterproofing was carried out with FPO/TPO synthetic membranes, which are durable, recyclable and free of plasticisers harmful to human health. External joinery uses PVC profiles with triple glazing and low-emissivity coatings, designed to reduce both heat losses and acoustic transmission. Indoor lighting is fully based on LED fixtures, while heating, ventilation and air-conditioning are managed through a Building Management System (BMS). Combined with these measures, the design is expected to deliver up to a 40% reduction in operational energy consumption compared with a conventional reference building of the same size [9], [12].

3.5 Construction and demolition waste management

A site-specific Waste Management Plan (WMP) was elaborated in line with OUG 92/2021 [6] and Order 756/2019 of the Ministry of Environment [7], structured according to the waste hierarchy of Directive 2008/98/EC [3], illustrated in Figure 3.

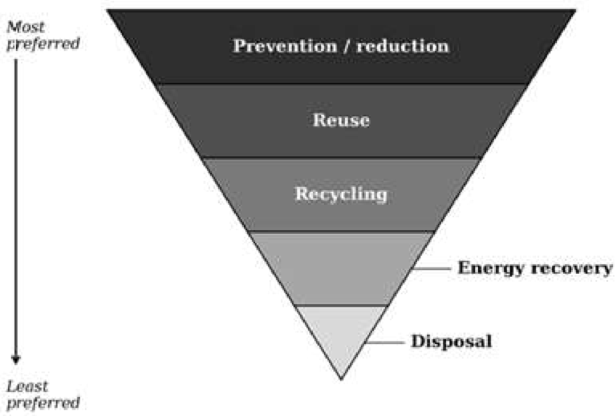

Fig. 3 Waste hierarchy applied to the construction and demolition waste management plan

Estimated waste composition during execution included: inert mineral waste (concrete, brick, mortar) accounting for the largest share, treated and untreated wood, ferrous and non-ferrous metals, plastics and packaging (about 10%), and other non-hazardous materials such as ceramics and plaster (about 15%). Separate collection points were set up on site, equipped with labelled containers and signage explaining handling procedures.

Recovery operations targeted the highest possible position on the waste hierarchy. Crushed concrete and brick were reused as aggregates for foundation backfill and non-structural layers; timber elements were reused as temporary scaffolding and formwork after integrity checks; metal scrap was sent to authorised recycling facilities; plastics and packaging were collected by licensed operators. Overall, the site achieved a recovery rate exceeding 60%, in line with the project target of 70% set in the WMP, significantly reducing the volume of waste sent to controlled landfills [3], [7].

3.6 Comparison between estimated and observed impacts

A post-construction comparison between the values predicted in the initial environmental documentation and those observed during execution revealed three main findings [14]. First, real noise and dust levels were below the predicted maxima, owing to the use of low-emission machinery, daily watering of dust-prone surfaces and temporary acoustic panels. Second, the volume of construction waste fell within the predicted range, but the recovery rate was higher than planned, confirming the effectiveness of source separation. Third, the impact on biodiversity was effectively negligible: pre-construction surveys had already indicated the absence of protected species in the immediate vicinity, and field observations during works confirmed this evaluation.

These results should be interpreted considering the limitations of the study, namely the relatively short post-construction monitoring window and the absence of detailed life-cycle carbon emission data.

3.7 Site-level mitigation measures and environmental management plan

The mitigation strategy implemented on site combined technical, organisational and educational components, structured into a project-specific Environmental Management Plan (EMP) prepared at the design stage and updated during execution, in accordance with the requirements of ISO 14001 [8] and ISO 45001 [18]. Technical measures included the installation of temporary anti-dust barriers along the construction perimeter, daily watering of access roads and excavation areas, the use of compliant construction machinery with reduced exhaust and noise emissions, and the placement of impermeable trays under stationary equipment to capture accidental fuel or lubricant leakage. Surface runoff was directed through temporary settling basins before being released into the local pluvial network [19].

Organisational measures focused on circulation and storage. Dedicated zones were delimited for raw materials, hazardous substances (paints, solvents, fuels) and waste streams, each provided with appropriate signage and containment. Heavy-vehicle traffic was scheduled outside school-arrival and -departure intervals to minimise community disturbance, and a single access point was used to reduce the dust footprint. Educational measures included monthly training sessions for site personnel and subcontractors, covering environmental legislation, the safe handling of hazardous materials and the immediate response to spills or other environmental incidents. The combined effect of these measures, validated by daily site monitoring records, kept all measured environmental indicators below the legal thresholds throughout the works.

The EMP also defined responsibilities and reporting flows. The site manager was designated as the operational owner of the plan, supported by a dedicated environmental officer in charge of daily inspections, while the consulting engineer (diriginte de șantier) verified compliance and reported monthly to the County Environmental Protection Agency of Galați [13]. This three-level structure ensured both technical rigour and procedural traceability and is recommended as a transferable template for similar small public-interest projects in rural areas.

3.8 Quantified energy and waste performance indicators

To complement the matrix-based assessment with measurable indicators, a set of operational performance figures was extracted from the design documentation and from the first months of post-completion monitoring. Table 5 reports the most relevant values expressed in units commonly used in international building-performance reporting. The reference (baseline) values correspond to a conventional building with the same floor area and functional programme, designed without the sustainable measures described in Section 3.4 and managed without source separation of construction waste.

Table 5 Selected performance indicators for the Nicorești medical center

Indicator	Reference	Project	Reduction / Gain
Specific heating demand (kWh/m²·year)	≈ 95	≈ 58	−39%
Specific electricity demand (kWh/m²·year)	≈ 65	≈ 40	−38%
Construction-waste recovery rate (%)	≈ 25	> 60	+35 pp
Hazardous-waste fraction (% of total)	≈ 3.5	< 1.5	−2 pp
Site water consumption (l/m² built)	≈ 220	≈ 180	−18%

The reductions in specific heating and electricity demand are consistent with the upper bound (40%) reported for the combined effect of envelope upgrades, LED lighting and BMS controls in the recent literature on near-zero-energy buildings [15]. The construction-waste recovery rate exceeds both the local baseline and the 70% target set by Directive 2008/98/EC for non-hazardous construction and demolition waste [3]. The reduced share of hazardous waste reflects the deliberate choice of low-VOC paints and adhesives, mineral-based insulation and chlorine-free roofing membranes [9]. Site water savings are attributable to the dust-control protocol, in which fixed quantities of water were applied to specific surfaces according to a daily schedule, instead of continuous, undirected wetting.

4. CONCLUSIONS

The integrated assessment carried out for the Multifunctional Medical Center in Nicorești demonstrates that small-scale rural healthcare projects can achieve a balanced environmental performance when the EIA process is integrated from the design stage [4], [11]. The execution phase generates the highest pressure on environmental factors, with an aggregated score of 54/120 corresponding to a moderate and reversible impact, dominated by noise and air-quality stressors. The operation phase, in contrast, delivers predominantly positive effects, with social accessibility scoring 15/15 and tangible reductions in transport-related emissions for the served communities [14].

Sustainable design choices — mineral-wool insulation, FPO/TPO membranes, triple-glazed PVC joinery, LED lighting and BMS controls — are estimated to reduce operational energy consumption by up to 40% [12], [15], while a structured Waste Management Plan enabled a recovery rate exceeding 60% on site [3], [6]. The comparison between estimated and observed impacts confirmed that mitigation measures, when applied consistently, can keep effects well within the limits set by Romanian and European environmental legislation [2], [4], [20].

Three practical recommendations emerge from the case study. First, environmental impact assessment and mitigation planning should be performed at the design stage rather than as a regulatory afterthought [11], [13]. Second, post-construction monitoring should be extended to at least 24 months and supported by IoT instrumentation, to capture seasonal variations and cumulative effects. Third, full life-cycle assessment (LCA) should become standard practice for public-interest buildings, especially those serving vulnerable rural communities, to align local projects with the European Green Deal [17] and the Energy Performance of Buildings Directive [15].

The main limitations of the study should also be acknowledged. The post-construction monitoring window covered only the first months after completion, which is too short for a reliable assessment of medium- and long-term effects such as material degradation, infiltration phenomena or seasonal variability of energy consumption. Quantitative data on construction-phase carbon emissions, including the transport of materials and on-site fuel use, were estimated from generic literature values rather than measured on site, which limits the specificity of the carbon balance [16]. Finally, the comparison between predicted and observed impacts was constrained by partial access to the original Environmental Impact Study, particularly to its annexes on dust dispersion modelling and acoustic simulation. Future research should therefore extend monitoring to a minimum of 24 months, integrate IoT-based real-time measurement of PM, noise, humidity and energy use, and apply a full LCA covering the entire life cycle of the building, from raw-material extraction to demolition [16], [17].

4.1 Implications for practice and policy

Beyond the specific case of Nicorești, the findings carry several implications for engineering practice and for local public policy. Designers of small public buildings are encouraged to treat the EIA process as a design-support tool rather than as a procedural obligation, integrating its outputs into structural, architectural and MEP decisions from the conceptual stage [11]. Contractors should adopt site-specific Environmental Management Plans even when not explicitly required by the environmental permit, to consolidate good practice and to facilitate future certification under voluntary schemes such as ISO 14001 [8]. Finally, local authorities are recommended to establish minimum requirements for post-construction environmental monitoring in public-investment contracts and to support, through targeted funding instruments, the digitalisation of monitoring activities through low-cost IoT sensor networks. Such measures would substantially improve the quality and comparability of environmental data available for rural construction projects in Romania, contributing to the wider objectives of the European Green Deal [17] and of the national strategy for sustainable development.

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