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Management for Stability Analysis and Design of Slope Reinforcement on Landslides Areas

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Abstract: The current national and European requirements set the economy from the construction sector to new approaches to investment and construction management. The scope of design, execution and management of the investment begins to have different priorities and challenges.Slopes and landslides are one of the most common and most dangerous geological threats in Poland and beyond. They cause losses and destruction not only in infrastructure but also in the environment. They are a huge threat to people and their functioning in the environment.The presented document is aimed at presenting concepts and solutions for landslide protection and slope stabilization at existing damaged road sections. The main design task of this work is to restore to full technical efficiency the analyzed body of the existing poviat road No. 1475S Żywiec - Rychwałd in Żywiec at 0 + 405 km to 0 + 455 km by stabilizing an active landslide in the entire known range of its occurrence and ensuring safety for road users.

Calculation were made by the GEO5 program, Slope Stability module and Wall analysis. Firstly, the soils layers was averaged and defined. The object was included in the third geotechnical category in complex soil conditions. Then, soil parameters were assigned and modelled in accordance with geology. Finally, loads and groundwater levels were defined and results obtained. The shape of the slope was then given and calculations were made. It uses: Bishop, Fellinius, Spencer, Janbu and Morgenstern-Price methods for stability analysis. The calculations are mainly based on Eurocode 2, 3 and 7 and the technique design in this case is called the Tessin Wall.Construction investment management requires a new cicrle economy approach for building materials and project solutions.

Keywords: Slope, Landslide, Protection, Engineering, Construction, Pike, Soil, Eurocode 7, Management

1. Introduction

Slopes and landslides are one of the most common and most dangerous geological threats in Poland and beyond. They cause losses and damage not only in infrastructure but also in the environment. They are a huge threat to people and their functioning in the environment [16].

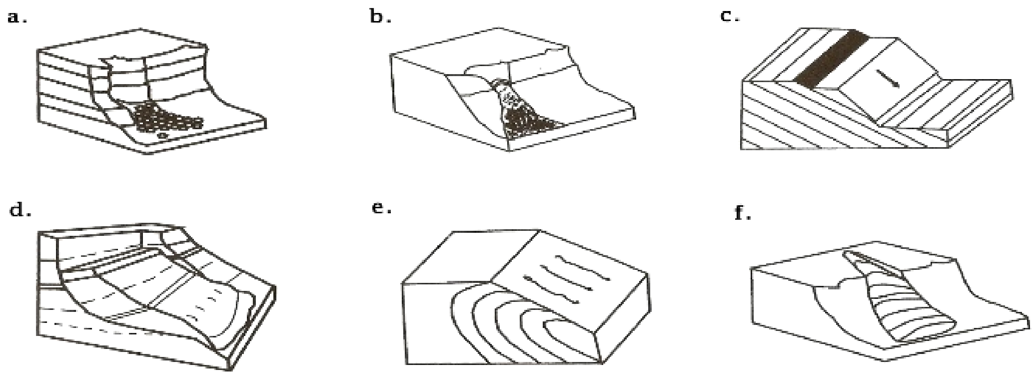

Figure 1Different types of slopes

In the vast majority of cases the essence of the issue of stability of slopes is in the excess of soil shear strength over shear forces. The factors that have the greatest impact on the unfavorable arrangement of these values relative to each other are, among others, a large variety of soil layers, ground water level or slope [17]. Geotechnical assessment of phenomena in the ground depends on estimating the degree of cooperation between the building and the ground [13], [14].

Both concepts, landslides and escarpments function in close dependence and one phenomenon does not actually exist without the other. In Poland, the area most vulnerable to landslide phenomena is the south-eastern part of the country, especially the Carpathian regions. In addition, landslides often occur in the coastal area as well as in the Kielce and Masuria Voivodeships.

2. Theoretical background

2.1. Methods of strengthening and reinforcement for slopes

There is a lot of methods and ideas for the most effective and long-term protection for slopes in the literature. The implementation of appropriate types of finishing and rehabilitation works or suitable constructions reduces to a minimum activities related to the removal of erosive damage. Even a completely statically secured slope is exposed to soil erosion, which leads to the formation of dangerous landslides.

2.1.1. Methods of strengthening for slopes

The first way may be geoagrotechnical protection of slopes. This method is based on securing slopes with chopped straw and a mixture of grass mixed with water, which, when unfolded on the slope, combine to form a whole, which gives them protective properties for the slope.

Another important activity for strengthening slopes is planting and compacting so that the vegetation receives 60 - 80% of rainwater.

The fermentation process of sewage sludge and composts for strengthening slopes and slopes in the humus process should be the increasingly preferred method of securing slopes by modern engineers and designers, because this method is based on the use of renewable raw materials.

A common way to protect slopes and slopes is also the use of geotextiles and shading nets, at least 5 cm thick, which not only protects the slope from erosion, but also allows you to continue work at any time of the year [5], [13], [14], [15], [19].

Gabions are another popular solution for securing landslides and slopes. It is a system of meshes made of galvanized wires with a diameter of 2 - 3.5 mm, which is filled with large aggregate and shaped in any way. Thanks to this structure, the bearing can freely drain and not plasticize the soil, and the gabions themselves are a great stabilizing load [21].

The Pneusol method is also popular in Poland and it is based on the use of worn tires from retaining wall structures [6].

2.1.2.Methods of reinforcement for slopes

The main method of strengthening slopes according to Eurocode are three types of retaining structures. The first method of securing slopes by Eurocode 7 concerns use of massive (gravitational) retaining walls, which usually defines several geotechnical parameters (γ, ϕ, c). The second type are walls recessed in the ground, e.g. sheet piling, mainly made of steel, reinforced concrete or wood, which are often fixed with anchors or struts to the ground. The last type of retaining structure is a wall with complex structure and it can fixed the first and the second one method together [1].

It is also worth mentioning about other methods of reinforcement, e.g. pinning, filter buttresses, concrete injections into the ground, drainage wells, the TessinWall technology, pikes and micropikes [9, 10, 11].

2.2. Methods for checking stability of slopes

There are many methods in the literature for checking the stability of slopes. The most important factor determining the choice of the calculation method is the awareness of the occurrence of the largest number of factors taken into account in the calculation algorithm. The result of calculations is usually the safety factor, the most important for the assessment of slope stability.

2.2.1. Limit balance methods

Empirical methods for determining the stability of slopes and slopes can be divided into three sections:

- limit balance,
- stress limit state,
- induced friction resistance.

In practice, despite many proposed methods of analysis, several of them are most often used. Usually these methods are derived from the analysis of the limit equilibrium of forces acting parallel to the slip surface, for which the equilibrium index F is determined:

$$\boldsymbol{F} = \frac{\sum \boldsymbol{U_i}}{\sum \boldsymbol{Z_i}}, \qquad (1)$$

where:
U_i - generalized holding forces,
Z_i - generalized loading forces.

Slope stability consisting of cohesive soils should be separately tested for irrigated and dry soil [16]. In the case of irrigated soil, drainage pressure should be taken into account, while for dry soil the most important to maintain balance is the slope angle, which should be equal to or less than the angle of internal friction of the soil. In the case of cohesive soils, stability testing is a more complex calculation process.

2.2.2. Methods for checking the stability of slopes from cohesive soils

The initial assumption for checking statistics of cohesive soil slopes is to assume a circular slip surface [13, 14]. Such situations usually occur within layers of low strength. The essence of determining the limit equilibrium is the combination of normal stress operations along the slip surface. In practice, the most popular test method is the strip method, according to which massive settling is divided into vertical parts and determined forces occurring in it, when some of the developed methods currently used in computer software for statistical calculations of the slope are available. The first of these is the Fellenius method, which only takes into account the condition of moment balance [4, 11, 12, 18, 19]. Another often used in calculations of slope stability is the Bishop method, which takes into account the two-way interaction of adjacent strips and the condition of equilibrium of moments [4, 11, 12, 19], and the calculation model is carried out based on iteration [21]. Iteration is carried out until a situation is achieved when the results for the coefficients differ from each other by less than the value assumed in advance. The third method that is equally often used is the Janbu method, which bases its assumptions on inter-band interactions, while the equilibrium condition is the sum of projections of forces on the horizontal axis [4, 12, 20]. The shape of the slip surface has no effect on the value of the stability factor [21]. The basis of this calculation methodology is the Bishop equation.

2.3. Pikes according to Eurocode 7

Nowadays, engineering objects are increasingly demanding and have to deal with difficult geotechnical conditions. Therefore, pike foundations are starting to become a more and more popular foundation method. These types of foundations transfer the load from the structure through the bottom and the side surface of the pike.

Pikes should be designed based on:
- results of static test loads,
- analytical or empirical calculation methods,
- results of dynamic tests,
- checking the behavior of similar pike foundations [2].

During pike dimensioning, the arrangement of layers in the soil has the greatest impact on their selection. In a situation where a weak layer surrounds the pike's sidewall, it will be characterized by high compressibility, which will have a direct impact on the significant susceptibility of the pike to deformation and very limited shear strength, which may result in construction disasters. Therefore, the essence of designing pike foundations is to embed them in layers of strong soils, such as slate, rock [18], [20]. The load on the side of the pike is analyzed by dividing it separately on the pressure from the ground from the side of the loaded ground and the resistance on the opposite side. It appears with the difference of vertical stresses [3].

According to Eurocode 7, in order to demonstrate that the foundation will carry the designed interference load with a sufficient load safety margin, the following inequality must be met for all cases and load capacity combinations [24]:

$$F_{c;\,d} \leq R_{c;\,d} \qquad (2)$$

2.4. Retaining structures according to Eurocode 7

Retaining structures are engineering objects that are usually dimensioned for the transition from one ground level to another or to limit water tanks [7]. The rules and calculation procedure for retaining structures are contained in Chapter 9 Eurocode 7. It mainly contains recommendations and requirements for the correct design of retaining structures. Annex C of Eurocode 7 sets out the methodology for calculating the limit values for soil pressure and repulse [8]. The calculations consider primarily deformations and displacements of the designed retaining structure, but also the results of the calculations taking into account changes in the water level, changes in time and space of the land mass, make a dig from the front of the designed structure, weight from existing structures, impact of subsidence and extreme weather conditions (e.g. frost) and combinations of effects [7].

3. Materials & experiments

3.1. Location

The beginning of the project is located - according to the kilometer of the road at 0 + 400 km and the end at 0 + 455 km in Żywiec.

Figure 2. a. Views for slope

The area of the active landslide covered by the study is located on the plots:

Table 1. List of plots in the landslide area

No.	Number of plot	Owner, address	Comments
1	1713/2	State Treasury, Krasińskiego 13 Street, Żywiec	dr
2	1733/1	Commune of Żywiec, Krasińskiego 13 Street, Żywiec	dr
3	1734	ŻywiecPoviat, Krasińskiego 13 Street, Żywiec	RIIIb, ŁIII, ŁIV,PsIV,LsIV
4	1735	Regional Water Management Board in Krakow, Management Board of the Soła and Skawa basin with headquarters in Żywiec	Wp
5	1741	ŻywiecPoviat, Krasińskiego 13 Street, Żywiec	LsV

3.2. Description and assessment of soil and water conditions and geological conditions

During the geological works, anthropogenic deposits (drilled in OG-2 and OG-6 wells) associated partly with the embankment of the road in the form of mixed stones, old asphalt, glass, bricks and organic parts (roots) were found. This uncontrolled embankment is associated with the wild garbage dump occurring in this area, i.e.

on the entire southern slope below the road from the OG-1 to OG-3 well together with the entire landslide colloquium.Quaternary soils developed in the form of loam and sandy loam with stones, and at the bottom of the weathered clay shale occur throughout the entire surface of the slope falling south towards the Moszczankastream.Paloogene (oligocene) deposits are represented: sandy and clay shales (with a clear difference in shear strength Rc), sometimes separated by sandstone inserts. Slates alternate in the form of cracked and very cracked slate with less-cracked, less solid, slate. Coarse (conglomerate) sandstones, cracked, were drilled in the OG-1 well and along with the depth changed the grain fractions into smaller ones.The water table is usually free, and only locally it has a slightly thrust character - in places where aquifers are covered with poorly permeable sediments. The water surface is usually at a depth of 2-4 m, only locally deeper.

Pursuant to the Regulation of the Minister of Transport, Construction and Maritime Economy of 25 April 2012 on determining the geotechnical conditions for the foundation of building structures, the building has been included in the third geotechnical category in complex soil conditions.

3.3. Construction concept

Combination of materials [22, 23, 24]

Pikes
- Concrete: C30 / 37
- Reinforcement: IPE 140 Steel S235 profile

Reinforced concrete retaining structure
- Structural concrete: C25/30
- Primer concrete: C8/10
- Exposure class: XC3
- Maximum w/c ratio: 0.50
- Minimum cement content: 300kg
- Minimal reinforcement cover thickness c_{nom}: 50mm
- Reinforcing steel: A-IIIN (RB500W)

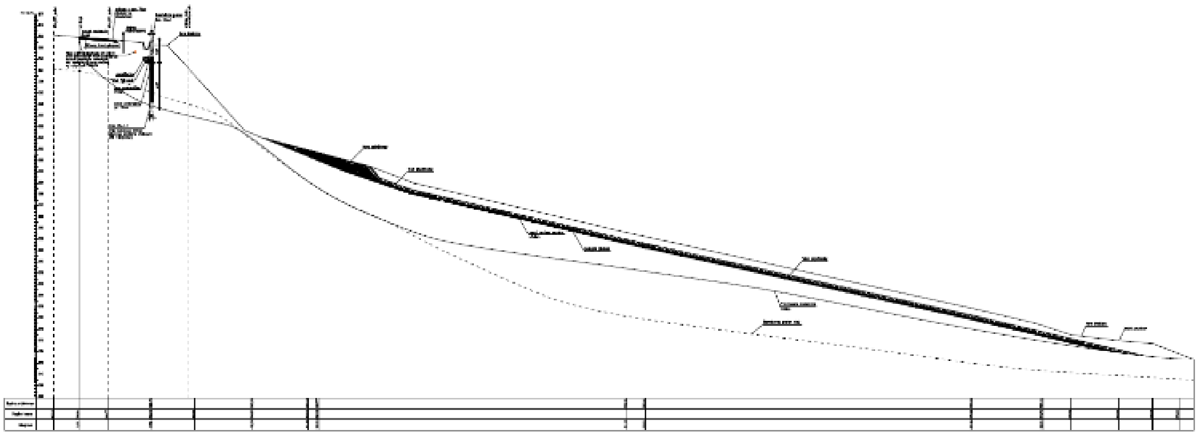

Figure 3. Transverse section

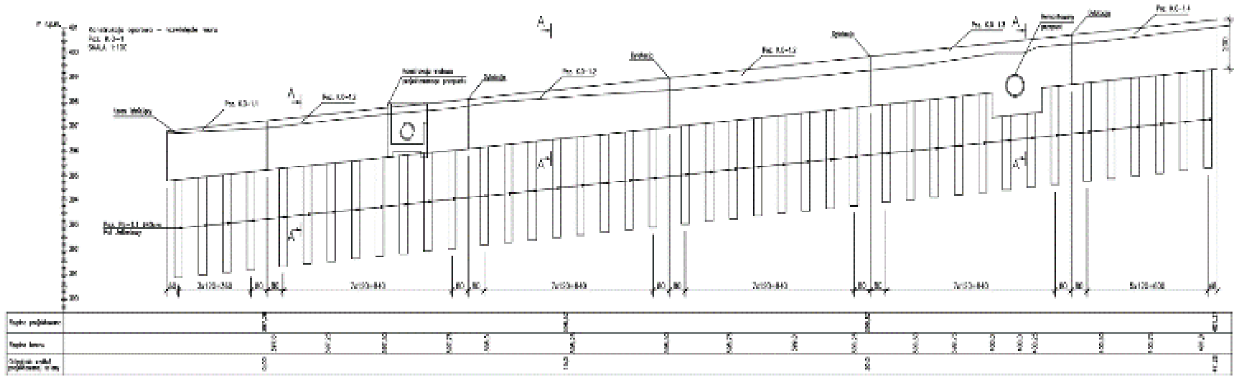

Figure 4. Retaining construction. Wall expansion

4. Result

Calculations were made using the GEO5 program, Slope Stability module and Wall analysis. The first step of the project was to average and define the tested soil layers in the place where the slope protection is to be designed.

The next step was to assign optimal values to individual soil subsoil parameters. The next element of the project was the task of the optimal slope shape for the created computational model, based on the slope stability analysis without the retaining structure. Computational simulations have shown that the slope in the adopted model does not meet the requirements, and the use of slope stability is:

• according to the Bishop method: 101.1%
• according to the Fellenius method: 103.2%
• according to the Janbu method: 101.3%
• according to the Morgenstern-Price method: 101.8%

and the escarpment is falling - the results of numerical calculations coincide with data from in situ tests for the analyzed area. Compliance in most cases oscillates around 100% - i.e. very good. This shows the model's compliance with the real issue.

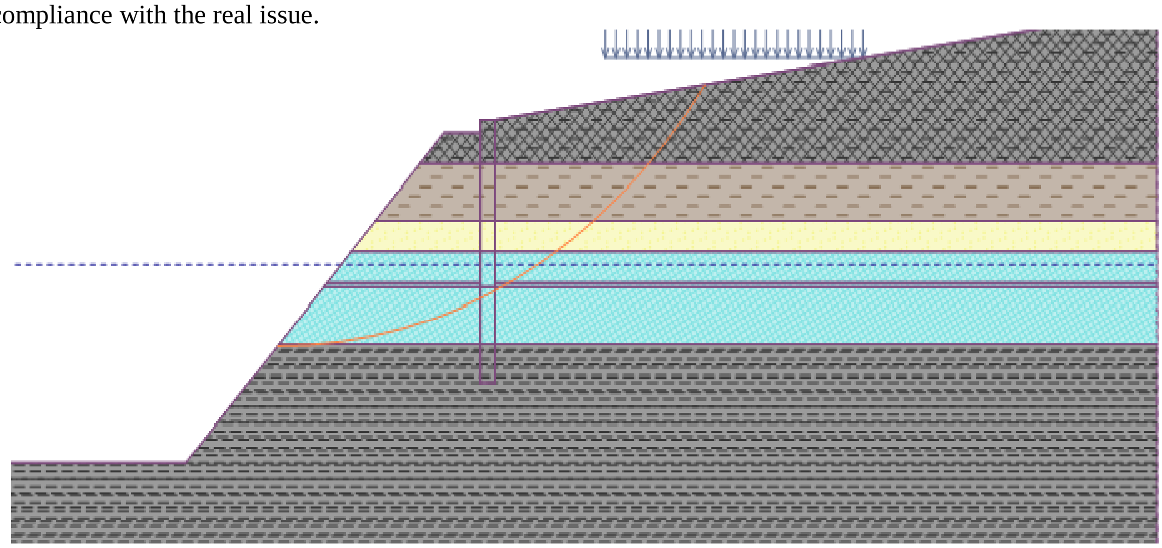

Figure 5. Slope stability analysis without retaining structure

The results of in situ tests and numerical analysis indicate a very high consistent risk of the linear construction in question - the road at 0 + 405 km and at 0 + 455 km in Żywiec.

The next step in the project is to design an optimal retaining structure - a solution in the form of palisades was chosen for which simulations of spacing and diameter were carried out. Suitably converted variants gave the optimal solution to meet load capacity conditions. The last design step was a calculation simulation for checking

the slope stability. The slope stability utilization using the designed structure is successively for each:
- Bishop's method: 57.0%
- Fellenius method: 54.4%
- Spencer method: 50.6%
- Janbu method: 49.0%
- Morgenstern-Price method: 49.3%

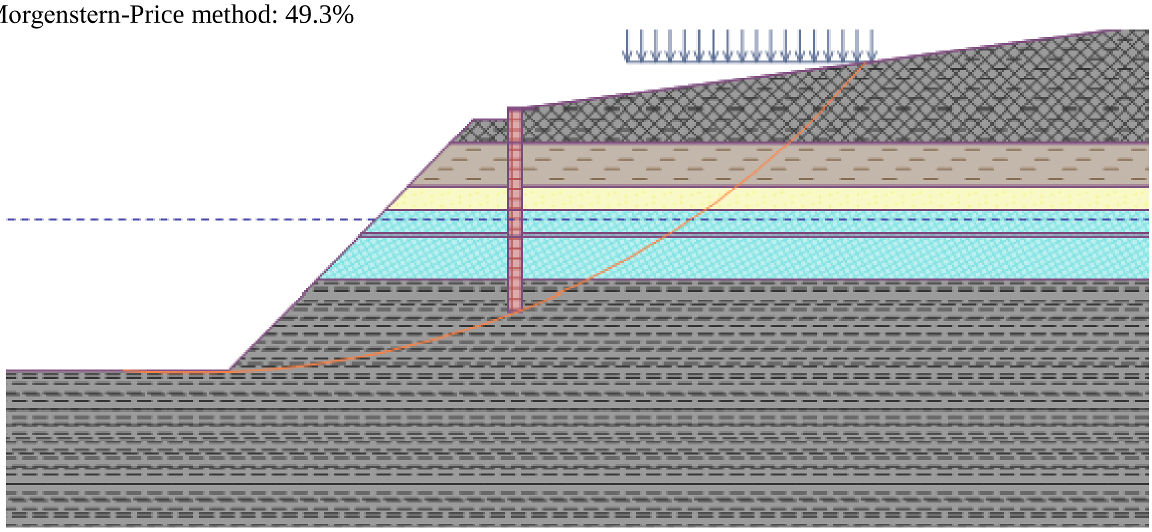

Figure 6. Slope stability analysis with retaining structure

The Tessin Wall technology is the optimal method chosen to strengthen the embankment. The photo below shows damage to the roadway near the landslide, as a result of badly drained rainwater.

5. Discussion & conclusion

The Shear Strength Reduction option allows perform a finite elementslope stability analysis, and compute a critical strengthreduction factor for the model. The critical strength reductionfactor is equivalent to the "safety factor" of the slope.The construction material have been modelled as elastoplasticmaterial whereas top soil and the rock layers have been modelled as elastic-ideally plasticmaterial [20]. Mohr-Coulomb slip criterion has been utilized forthe slip-surface stability analysis. The models meshed uniformlyby elements which can effectivelyincorporate the non-linear displacement variations within thenodes of the each finite element as well as can capture localplastic strains. The analysis considers the stability of the entire model when the analysis is computed. However, there are circumstances when one may wish to focus on the stability of a particular area of themodel.Designed by the selected method and with the initial assumptions given for the adopted calculation models, the structure of the road protection in question, as a reinforced concrete wall 2.0m high, mounted on a palisade of concrete pikes with a diameter of 40cm spaced every 1.2m, reinforced with a steel profile IPE140, meets all conditions perfectly optimally designed (provide values):

<u>Maximum values of displacements and internal forces</u>
Maximum displacement = -1.0 mm
Maximum displacement = 0.2 mm
Maximum bending moment = 5.04 kNm
Minimum bending moment = -12.85 kNm
Maximum cutting force = 12.92 kN

<u>Checking the composite cross section according to EN 1994-1-1</u>
All construction phases were included in the calculations.
Calculated section load factor = 1.00
<u>Forces per profile</u>
Mmax = 15.42 kNm; Q = 0.27 kN
Qmax = 30.33 kN; M = 1.26 kNm

Checking max. Torque Mmax + Q
Checking the shear cross-section:
Q / VRd = 0.002 ≤ 1 Meets the requirements
Checking the folded section for bending:
Mmax / Mpl, N, Rd = 0.284 ≤ 0.9 Meets the requirements
Check the max. Shear force Qmax + M
Checking the shear cross-section:
Qmax / VRd = 0.195 ≤ 1 Meets the requirements
Checking the folded section for bending:
M / Mpl, N, Rd = 0.023 ≤ 0.9 Meets the requirements

The retaining structure is a reinforced concrete wall mounted on a palisade. Such a method is an additional drainage method for rainwater for the exposed area, and what is more, the planned building intentions, taking into account the integrated and developed protection of all-natural values, will not have a negative impact on the bed of the Moszczanica stream or the surrounding area.In the present case, the construction model should have necessary structural strength to transmit thelateral loads imposed on it by the movement of weak slopelayer, ultimately to the hard rock layers below.In line with the European Green Deal the commission will reinforce the monitoring of national plans and measures to accelerate the transition to a circular economy as part of refocusing the European Semester process to integrate a stronger sustainability dimension.Architectural, engineering and detailed designs as well as the stages of management, execution and monitoring of geotechnical structures begin to have other priorities [18], [19]. The new commission will also update the Monitoring Framework for the Circular Economy, as CE is starting to have a priority role in construction management and investments. Relying on European statistics as much as possible, new indicators will take account of the focus areas in this action plan and of the interlinkages between circularity, climate neutrality and the zero pollution ambition. At the same time, projects under Horizon Europe and Copernicus data will improve circularity metrics at various levels not yet reflected in official statistics.Indicators on resource use, including consumption and material footprints to account for material consumption and environmental impacts associated to our production and consumption patterns will also be further developed and will be linked to monitoring and assessing the progress towards decoupling economic growth from resource use and its impacts in the EU and beyond.

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