University of Beira Interior - Faculty of Engineering

Course:

Circular Resource Mapping: Identifying CO_2-Absorbing Waste for Construction Innovation

Theoretical Part

The course "*Circular Resource Mapping: Identifying CO_2 -Absorbing Waste for Construction Innovation*" is part of the New European Bauhaus Academy (NEBA). It is funded by the Circular Bio-Based Europe Joint Undertaking (CBE JU) under the Horizon Europe Program (Grant Agreement No. 101160532). The course offers conceptual and scientific foundations to demonstrate how regional bio-based residues can support sustainable and circular innovation in construction.

The main idea of the course is that by-products from agriculture, forestry, and textiles are potential carbon sinks instead of just waste. When these residues are carefully classified, mapped, and used in material development, they can help reduce carbon emissions in the construction sector by capturing, mineralizing, and storing carbon dioxide as solid material[1]. The course offers a systematic approach for visualizing these resources using digital mapping tools like QGIS and Google Earth. These platforms create multi-layered datasets that link materials, industrial sectors, and environmental potential.

Residues absorb or fix carbon dioxide through natural carbonation and mineralization reactions. Over long periods, carbon dioxide reacts with silicates containing calcium and magnesium to form stable carbonate minerals. This process, a key part of the Earth's carbon cycle, sequesters carbon dioxide as solid rock for geological timescales. Recent technological advancements have sped up this mechanism in labs and industrial settings, reducing the timeframe to hours or days. The resulting carbon-negative materials are durable, strong, and environmentally beneficial.

Residues high in calcium oxide (CaO) and magnesium oxide (MgO), including slags, ashes, and dusts, effectively trap carbon dioxide. These materials easily react with carbonic acid to form carbonates. Organic residues like wool, straw, cellulose, and other biopolymers also help by increasing porosity, improving gas diffusion, and boosting the thermal and mechanical properties of composite materials. The mix of mineral and organic phases affects both the efficiency of carbon capture and the overall performance of the material[2].

Multiple factors influence the absorption and mineralization of carbon dioxide. The chemical composition of the residue determines the quantity of reactive oxides available for carbonate formation. Surface area and particle morphology affect the extent of solid-gas interactions. Moisture content facilitates carbonic acid formation, promoting ion exchange and precipitation. Temperature and pressure conditions alter the solubility and diffusion of carbon dioxide, while reaction duration and compaction influence the depth of carbonation. Optimizing these parameters enhances both carbon dioxide uptake and material strength.

Mapping the physical and chemical characteristics of residues supports regional planning for circular resource use. Integrating geospatial data on land use, industrial activity, and material flows identifies regions with significant innovation potential. For instance, forestry and textile industry clusters may enable organic residues from one sector to complement mineral residues from another, fostering industrial symbiosis. Thus, mapping serves as both a visualization technique and a strategic decision-making tool for advancing regional sustainability.

The course highlights that circular resource mapping includes both technical and cultural aspects. On the technical side, it involves analysing data, environmental indicators, and resources with digital tools. Culturally, it shifts community views by redefining waste as a regional asset that fosters innovation and bolsters local identity. This method aligns with the Bauhaus mission to combine scientific precision, aesthetic appeal, and inclusivity in creating regenerative and meaningful environments.

The course's theoretical framework shows that identifying and mapping carbon dioxide-absorbing residues is crucial for reaching regional carbon neutrality. Visualizing material flows helps policymakers, researchers, and industry leaders create systems that promote reuse and regeneration. This method enhances systemic sustainability by cutting emissions and creating new local opportunities based on existing resources[3].

"Mapping is more than spatial representation. It is a scientific and creative act that makes material potential visible, turning invisible waste into pathways toward a carbon-neutral future."

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This practical component focuses on the theoretical foundations of Circular Resource Mapping through structured digital activities. These exercises mimic the processes of identifying, categorizing, and mapping regional waste streams, especially those with potential for carbon dioxide (CO_2) capture, mineralization, and valorisation. The methodology combines environmental data analysis, digital mapping techniques, and collaborative problem-solving. Participants explore how spatial data can support circular innovation at the regional level [4].

Participants use open-source geospatial tools, including QGIS and Google Earth, to create interactive territorial maps that display multiple data layers. These layers consist of bio-based residue sources, the locations of industrial facilities, and potential areas for circular collaboration. This approach helps participants gain a comprehensive understanding of the connections between materials, geographic features, and industrial activities within a regional circular economy framework.

These exercises develop spatial and analytical reasoning by encouraging participants to explore the origins, movements, and potential reuse of materials to reduce environmental impacts. The module goes beyond technical instruction by combining data science with innovative ecological planning. Participants transform raw datasets into practical insights. The resulting maps depict the territory and highlight strategies for decarbonization, circular material use, and community-driven innovation.

The main goal is to show how geospatial technologies make previously hidden material flows visible and traceable. Mapping allows participants to see the connections between waste producers and potential users, helping to find local synergies that might otherwise go unnoticed. These activities demonstrate how spatial analysis supports evidence-based sustainability decisions. The curriculum emphasizes collaborative data interpretation, visual communication through mapping, and effective digital sharing of environmental information.

This practical work supports the mission of the NEBA initiative, which aims to combine scientific accuracy, aesthetic value, and social inclusion in a unified educational framework. By developing mapping skills, participants learn to turn abstract data into tangible strategies that promote a move toward a carbon-neutral future.

1. Introduction

Objective

This course offers participants practical experience in collecting, processing, and visualizing data on regional residues with potential for carbon dioxide absorption. The program aims to integrate scientific knowledge with territorial planning. Participants will examine circular design strategies using digital tools, including QGIS and Google Earth. Practical exercises will enable participants to analyse the relationships among waste generation, industrial processes, and environmental impact. These activities develop competencies necessary for designing construction strategies that minimize carbon emissions.

Rationale

Circular resource mapping integrates environmental knowledge, spatial representation, and data analysis to enhance territorial intelligence. Territorial intelligence refers to a region's capacity to understand, optimize, and manage its resource flows. Identifying and mapping bio-based and mineral residues capable of absorbing or reacting with carbon dioxide enables participants to transform local waste streams. This approach generates opportunities for sustainable innovation. This methodology supports the development of low-carbon materials and fosters collaboration among municipalities, industries, and research centres. Collectively, these efforts establish a framework that integrates scientific, geographic, design, and policy perspectives. Participants will use open-source data and geospatial tools to construct datasets that detail regional resource availability.

- They will analyse spatial relationships between sites of resource production and points of reuse.
- Participants will communicate sustainability challenges using clear visual evidence.

These activities demonstrate that digital literacy and data visualization are effective tools for supporting environmental awareness, local policy innovation, and strategic decision-making in sustainable construction. The course enables participants to connect theoretical knowledge with practical application. It provides the skills necessary to identify and utilize the latent potential of regional waste streams.

2. Practical Procedures

This section explains the digital workflow for the online course Circular Resource Mapping: Identifying CO_2-Absorbing Waste for Construction Innovation. The objective is to guide participants in collecting, organizing, and visualizing regional data on residues with potential for CO_2 capture or valorisation, using only Excel or Google Sheets for data entry and Google Maps for visualization.

Participants complete these steps individually and at their own pace, building a dataset on forestry and textile residues. After data entry, they plot records on a web map, using the attached Excel file and Covilhã regional maps as the case study and visual reference.

2.1 Data Collection and Preparation

Gather basic data on forestry and textile residues in your chosen municipality or region. Enter the information into a simple spreadsheet (Excel or Google Sheets), keeping a clear and consistent structure.

Step 1 - Selecting the Region of Study

Select one municipality or local area (such as Covilhã) as your study region.
Choose a region based on your knowledge, proximity, or access to local information.
Focus on areas with industries or small producers connected to forestry and textiles.

Step 2 - Identifying Sources of Residues

Identify potential sources of forestry and textile residues in the region.
These may include:

- Forestry residues: sawdust, bark, lignin waste, or wood ash.
- Textile residues: wool, natural fibres, or waste from textile factories.

Search public information (company websites, municipal data, or local reports) and record the details in your spreadsheet.

Step 3 - Definition of Data Fields

According to Table 1, organize your collected data using the format of the attached Excel template. Assign each column to a key parameter.

Table 1. Circular Opportunities and Implementation Steps

Field Name	Description	Example
Municipality / Region	The name of the area where the residue is produced.	Covilhã, Fundão
Residue Type	Forestry or Textile.	Textile
Material Subtype	Specific material name.	Wool, Wood Ash
Availability	Low / Medium / High.	Medium
Origin / Source	Name of the company or sector producing it.	Textile Factory, Sawmill
Quantity (optional)	Approximate annual amount (if available).	500 tons/year
Potential for CO_2 Capture / Valorization	Short note on why it is relevant.	“Contains CaO/MgO,” “Improves porosity for carbonation.”

This dataset becomes the base for creating a visual representation in Google Maps in the next section.
Participants can later upload coordinates manually or use the map search function in Google Maps to locate each site.

Figures 1 and 2 below illustrate the Excel file and the example maps used in this activity.

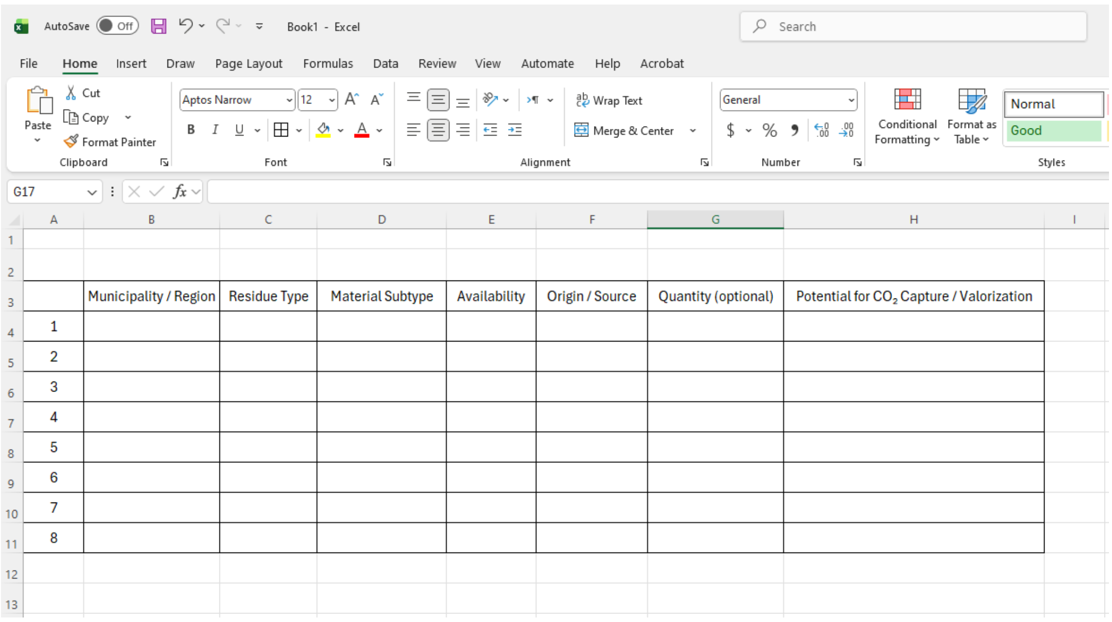

Figure 1. Example of the Excel Data Structure for Residue Mapping

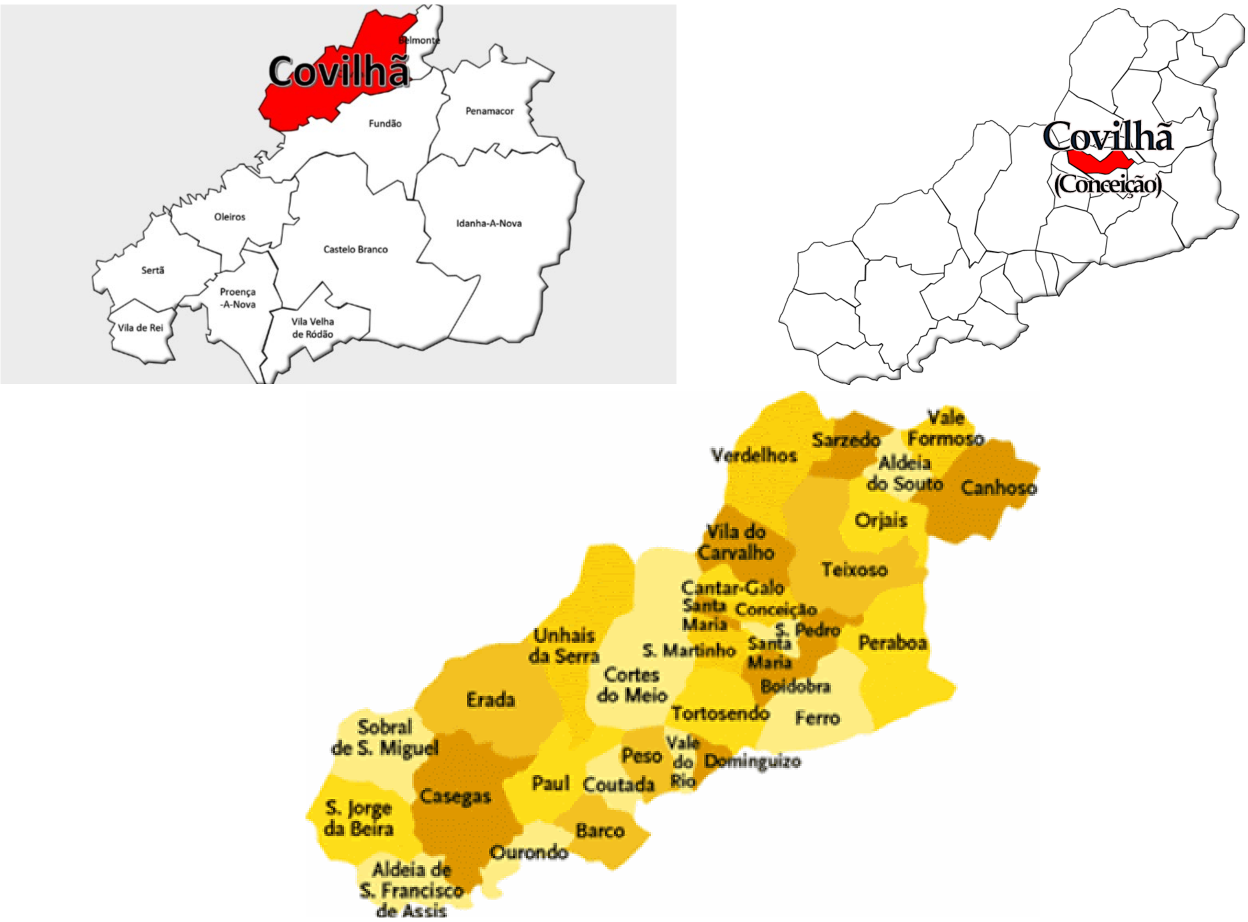

Figure 2. Map of the city of Covilhã and its surrounding municipalities

2.2 Visualizing Data in Google Maps (My Maps)

In this section, participants learn how to transfer the information collected in their Excel or Google Sheets file into an interactive digital map using Google My Maps [5].
The main goal of this step is to provide a visual understanding of the spatial distribution of forestry and textile residues and to identify potential connections between sources and nearby industries.

Step 4 - Importing Data into Google My Maps

1. Go to Google My Maps and sign in with your Google account.
2. Select “Create a new map.”
3. Use the Import option to upload your Excel or Google Sheets file (the same file created in Step 3).
4. In the import settings, choose the columns corresponding to “Municipality / Region” and “Residue Type” for labels and positioning.
5. Google My Maps will automatically generate map points based on each row of your file, displaying the geographic location of forestry and textile residues. (Figure 3)

Step 5 - Map Styling and Visualization

After the data is imported, participants can customize the map’s appearance to make it more readable and visually clear:

Use different colours to separate forestry and textile residues.

Add icons or custom markers to represent each material type (e.g., wool, wood ash, bark).

Include a short description for each point in the “Description” field, for example:
“Wool waste from textile factory, potential for CO_2 absorption.”

If desired, participants can create two layers, one for forestry residues and one for textile residues, to improve organization and clarity.

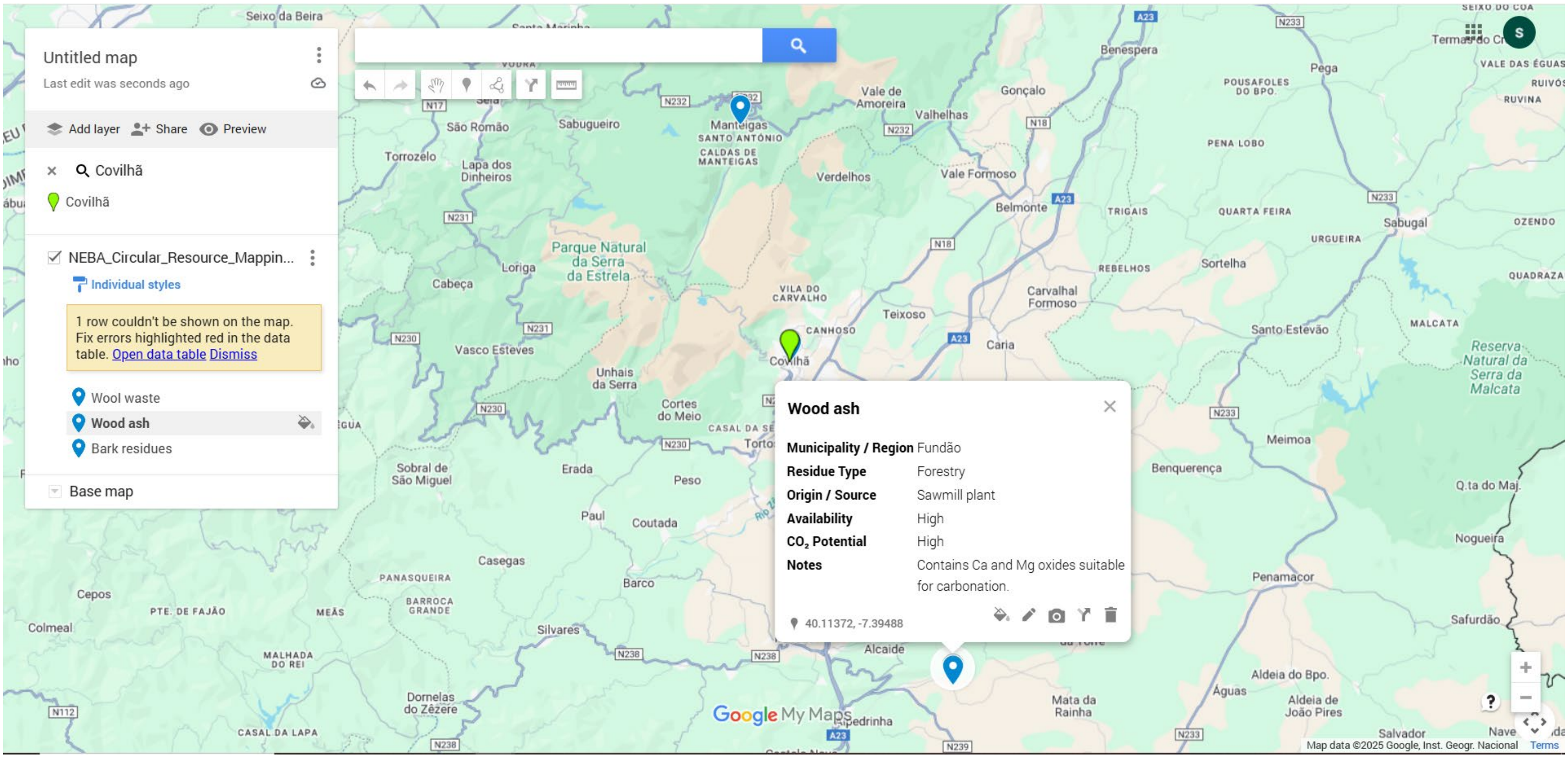

Figure 3. Data Visualization in Google My Maps

2.3 Data Interpretation and Local Analysis

Participants used Google Maps to visualize forestry and textile residues, analyzing spatial data to identify regional distribution patterns and opportunities for circular resource use. The analysis highlighted the impact of location, proximity, and material properties on potential collaboration and resource efficiency. Municipalities with the highest residue concentrations were identified, and connections between waste producers, such as sawmills and textile mills, and possible reuse sites, including construction sites, research centers, and material laboratories, were mapped. Residue accessibility was assessed and categorized as low, medium, or high based on collection, transport, and valorization feasibility.

Each participant prepared an analytical summary describing the primary residues, their geographic distribution, potential for carbon dioxide capture or reuse, and key opportunities for local collaboration. This process helped turn map-based observations into clear insights for decision-making. The summaries laid the foundation for the Circular Action Plan outlined in the next section.

2.4 Circular Action Plan

Building upon the spatial analysis and summaries from the previous section, participants now move from data interpretation to action planning. At this stage, participants translated analytical findings into actionable strategies for circular innovation. Each project commenced by articulating a primary circular objective, informed by previously developed data and maps. Objectives included minimizing textile or forestry residues, incorporating carbon dioxide-absorbing by-products into new material formulations, and enhancing collaboration between industry and research institutions. Participants identified two or three feasible opportunities for circular implementation within their local context[6]. For each opportunity, they analyzed the residue type, its origin, and potential applications. Subsequently, they assessed methods for reintegrating these materials into productive cycles and establishing links between waste generators and potential users.

Following the identification of opportunities, participants developed specific, time-bound actions. Short-term actions comprised low-cost tasks, including convening meetings among local industries or gathering supplementary data. Medium-term actions centered on research-driven initiatives and pilot projects to develop prototypes of circular materials. Long-term actions involved structural interventions, such as integrating circular principles into municipal or regional planning strategies. This temporal framework enabled participants to design feasible implementation pathways that accounted for available resources and local capacities.

The final phase emphasized stakeholder engagement, outcome evaluation, and reflective learning. The responsibilities of industries, municipalities, research centers, and community organizations were delineated to promote collaboration and shared accountability. Participants assessed anticipated outcomes, including reductions in carbon dioxide emissions, increased resource efficiency, and improved inter-organizational cooperation. Additional opportunities for sustainable innovation and green employment were identified. Material flows and stakeholder relationships were depicted using diagrams or maps to facilitate clear communication. Each participant provided a concise reflection summarizing key learnings, implementation challenges, and potential future actions. This concluding phase consolidated knowledge and enhanced comprehension of the circular planning process.

3. Analysis of Results

The analysis evaluated the extent to which participants applied circular design principles, waste reduction strategies, resource reuse, and spatial reasoning throughout the course. Each project was assessed for consistency between data interpretation, mapping outcomes, and the approach outlined in the Circular Action Plan, which is a structured framework for promoting circularity. The mapping-based insights generated in NEBA 3 complement the experimental findings of NEBA 2, establishing an integrated learning continuum between digital analysis and material experimentation.

The results indicate that participants developed a clear understanding of regional material flows and potential circular connections. Numerous projects identified synergies between the forestry and textile sectors, emphasizing opportunities for residue reuse and carbon dioxide (CO_2) reduction. The analytical process fostered critical thinking and enabled participants to convert environmental observations into practical actions [7].

Several projects introduced innovative methods, including small-scale pilot tests for carbon dioxide (CO_2) mineralization, the use of residues in local construction materials, and the integration of circular principles into community strategies[8]. Although project depth and scope varied, all submissions demonstrated meaningful engagement with sustainability, collaboration, and resource efficiency. The analysis confirmed that combining geospatial mapping with circular planning strengthens both technical and strategic competencies. This approach prepares participants to address real-world sustainability challenges. Participants completed the program with improved abilities to interpret environmental data, design context-specific sustainability solutions, and implement positive changes. These results demonstrate the transformative impact and educational effectiveness of the NEBA methodology, which integrates digital tools, scientific knowledge, and creative design thinking[9].

4. Conclusion

The Circular Resource Mapping course demonstrated the role of regional waste data in facilitating circular innovation. By integrating environmental science, geospatial analysis, and design thinking, participants effectively connected theoretical frameworks with practical implementation.

The course encompassed data collection, visualization, interpretation, and action planning, illustrating that mapping processes are both scientific and creative. This approach revealed previously unrecognized material flows, enabling communities to identify opportunities for circular resource utilization and carbon dioxide emission reduction[10].

Participants enhanced their analytical and strategic competencies and developed an understanding of how local material resources contribute to environmental objectives. The integration of mapping, collaborative activities, and reflective practices fostered a perspective oriented toward regeneration, innovation, and sustainability.

The program demonstrated that circular resource mapping extends beyond technical processes, serving as a transformative methodology that integrates stakeholders, data, and geographic context to advance carbon-neutral objectives.

5. Final Evaluation - Questions

1. What is the main goal of Circular Resource Mapping in the NEBA 3 course?
   a) Increasing tourism in the region
   b) Identifying CO_2-absorbing residues and planning circular strategies
   c) Improving national road networks
   d) Expanding textile production

   Correct Answer: b

2. Which digital tools are used for data visualization in this course?
   a) AutoCAD and SketchUp
   b) Excel only
   c) QGIS and Google My Maps
   d) Photoshop

   Correct Answer: c

3. What types of residues were mapped in the Covilhã case study?
   a) Plastic and electronic waste
   b) Forestry and textile residues
   c) Food and medical waste
   d) Agricultural water residues

   Correct Answer: b

4. How does mapping contribute to circular innovation?
   a) By increasing product sales
   b) By visualizing material flows to identify local synergies
   c) By reducing labour costs
   d) By replacing industrial machines

   Correct Answer: b

5. In data collection, why is it important to define clear parameters such as residue type and origin?
   a) To create colourful maps
   b) To ensure consistent, comparable, and traceable datasets
   c) To reduce file size
   d) To satisfy map design rules

   Correct Answer: b

6. What is the purpose of the Circular Action Plan?
   a) To create entertainment maps
   b) To translate analytical findings into actionable circular strategies
   c) To replace municipal regulations
   d) To design artistic posters

   Correct Answer: b

7. How can mapping support local collaboration between industries, municipalities, and research centers?
   a) By showing competition between sectors
   b) By identifying geographic proximity and shared resource opportunities

c) By forcing institutions to merge
d) By showing population density

Correct Answer: b

8. What are examples of short-, medium-, and long-term actions in circular planning?
a) Buying new vehicles, hiring workers, changing laws
b) Meetings/data collection; research/pilots; policy integration
c) Marketing, advertisements, branding
d) None of the above

Correct Answer: b

9. What competencies do participants develop through this course?
a) Cooking and agriculture
b) Spatial reasoning, sustainability planning, and data analysis
c) Textile manufacturing
d) Tourism management

Correct Answer: b

10. How can the knowledge and results from NEBA 3 be applied to future research or practical projects?
a) By staying unused in reports
b) By supporting material development, regional planning, and CO_2-based innovation
c) By promoting social media campaigns
d) By increasing the import of foreign materials

Correct Answer: b

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