# UNLOCKING VALUE FROM BY-PRODUCTS IN SLOVENIA'S BIOECONOMY

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Slovenia has significant raw material potential for the development of the bioeconomy. The Interreg Central Europe project TeBiCE focuses on Territorial Biorefineries for a Circular Economy and explores the utilization of biomass, by-products, and residues from primary production and the agri-food processing industry as new sources for producing high-value products. In Slovenia's contribution to the TeBiCE project, three key sectors were evaluated: fruit production and processing, oil production and processing, and the wood processing industry (timber). The potential for developing value chains in Slovenia was assessed using the Value Chain Generator® artificial intelligence tool (VCG.AI). Three value chains were outlined, where polyphenols, biochar, and pectin can be produced through the application of supercritical fluid extraction (SFE), pyrolysis, and enzymatic extraction. Biochar and polyphenols show high potential for exploiting by-product biomass in Slovenia. The VCG.AI tool was demonstrated to be an applicable resource for the fast and effective evaluation of by-products' potential for developing value chains.

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## 1 Introduction

Slovenia has a significant raw material potential for development of the bioeconomy, but it has similar as other Central and Eastern European countries sub optimally exploited potential. There is a great need to increase the growth potential of the bioeconomy, which will bring Slovenia not only new jobs, but also environmentally friendly technologies and better prospects for the future (Juvančič, 2021). By-products from primary production and the agri-food processing industry are potential source for production not only energy but also high value products produced by cascade concept of biorefineries (Juvančič, 2021).

Territorial Biorefineries for Circular Economy or shorter TeBiCE is the Interreg Central European project focused on removal the barriers in bio- and circular economies in the Central Europe area, in order to pave the way for the establishment of sustainable market for high-value bio-products. Project TeBiCE promotes the starting of new value chains, based on cutting-edge technologies and new business models, generating a more efficient and competitive economy. Project works on removing of legislative barriers and encourage more harmonized regulation to ensure a more efficient market for by-products and residues of primary production and agri-food processing in the Central Europe area. In project collaborate 8 project partners from 8 regions of Central Europe and 6 countries, Italy, Germany, Poland, Austria, Slovakia and Slovenia. The project started on April 2023 and will finished by the end of March 2026. [1]

In the present contribution the development of value chains (VC) in three sectors in Slovenia, fruit production and processing, oil production and wood processing, is presented and was performed by TeBiCE project. For evaluation the potential of by-products and residue of the selected sectors and for the development of high added value chain, the Value Chain Generator® artificial intelligence tool (VCG.AI) was used. In the contribution, the first the TeBiCE project is introduced, followed by introduction and application of VCG.AI in the context of the project.

[1] Project TeBiCE documentation: CE0100433_TeBiCE_en_en_20220224_083412

## 2 Introduction of TeBiCE project and by-products potential in Slovenia

Territorial Biorefineries for Circular Economy or shorter TeBiCE is the Interreg Central European project focused on the utilization of biomass, by-products, and residues from primary production and the agri-food processing industry as a new source for producing high-value products. In project is collaborate 8 project partners form 6 countries: Venetian Agency for Innovation in the Primary Sector – Veneto Agricoltura (Italy) – coordinator of TeBiCE project, National Institute of Chemistry (Slovenia), Fraunhofer Italia Research scarl-Innovation Engineering Center (Italy), Chemie-Cluster Bayern GmbH (Germany), University of Warmia and Mazury in Olsztyn (Poland), Kujawsko-Pomorskie Voivodeship (Poland), Carinthia UAS - non-profit limited liability company (Austria) and Slovak University of Agriculture in Nitra (Slovakia). The project started on April 2023 and will finished by the end of March 2026.

Project is divided in three work package (WP) where different aspects of project implementation are evaluated. Figure 1 schematically represents activities of separate WP of TeBiCE project. The potentialities for by-products and waste of the primary and agri-food sectors in Central Europe regions were evaluated in WP1. There was carried out an assessment of the situation and potential application of by-products and residues in Central Europe, including Slovenia. As part of project activities, the application Value Chain Generator® artificial intelligence tool (VCG.AI) was evaluated and applied by project. WP2, Pilot actions to define, by an "on-the-field" approach, constraints and potentialities for value chains, allow the establishment of value chains for the valorization of by-products and waste from residual biomass from the primary production and agri-food processing sectors and the adoption of business model oriented to circular economy. In the WP3, supporting a more harmonized policy scenario and regulatory framework for value chains in Central Europe area, the aim is to remove the institutional barriers and promote a more harmonized regulatory framework in the Central Europe to consolidate the establishment of market of by-products and waste from the primary and agri-food processing sectors. [2]

[2] Project TeBiCE documentation: CE0100433_TeBiCE_en_en_20220224_083412

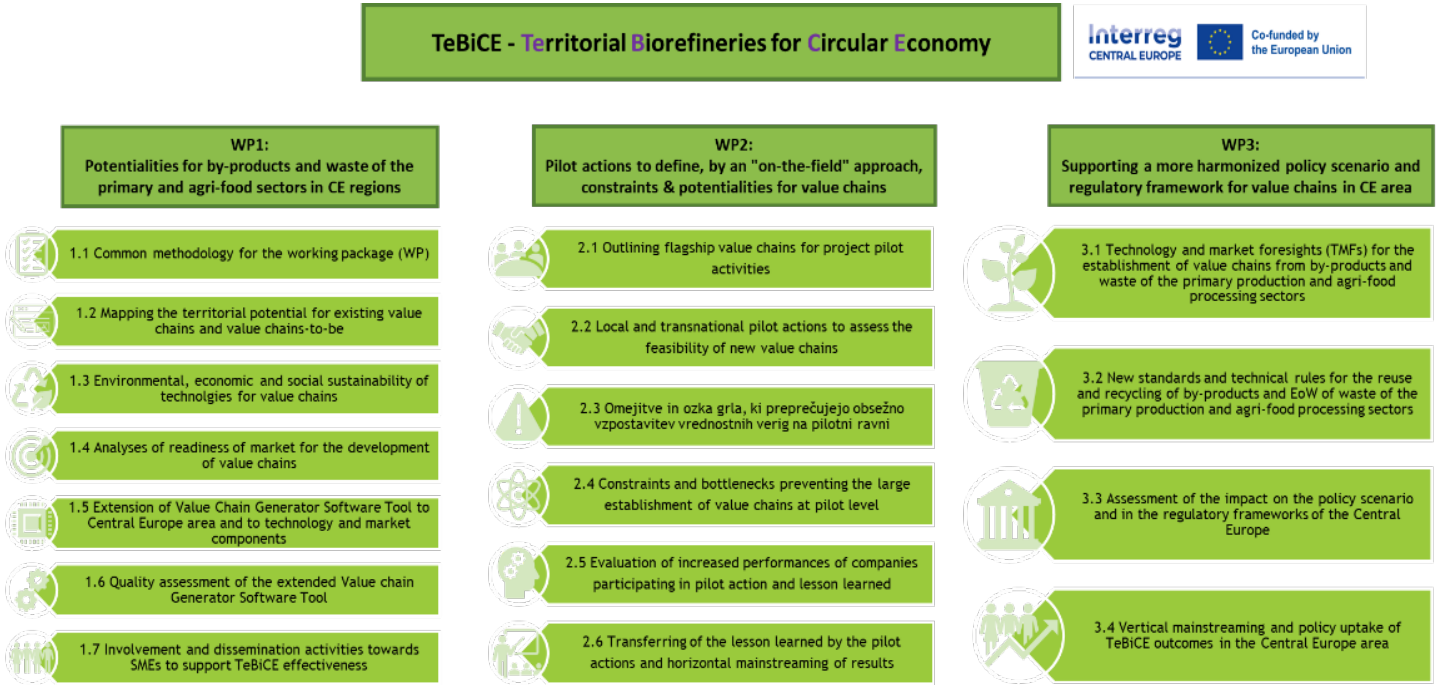


**Figure 1: The implementation of TeBiCE project.**[3]
Source: own.

[3] Project TeBiCE documentation: CE0100433_TeBiCE_en_en_20220224_083412

**Table 1: The potential of by-products evaluated in Slovenian VCs in TeBiCE project.**

| Evaluated by-product | High added value products | Middle added value products | Low added value products | References |
|---|---|---|---|---|
| **Grape pomace**  | • Polyphenolic compounds for natural antioxidants (extraction)<br>• Industrial enzymes for citrus acid production; (fermentation)<br>• Pectin for dietary fibers (extraction)<br>• Bio-ethanol, bio-butanol, bio-gas (fermentation)<br>• Poly-hydroxy-butirate (PHB) biopolymer (fermentation)<br>• Grape seeds oil (mill) | • Bio-chair (anaerobic pyrolysis)<br>• Bio-fertilizer (fermentation)<br>• Mushroom cultivation<br>• Functional food additives (mill) | • Animal feed<br>• Fertilizer<br>• Energy (combustion) | Beres, 2017<br>Sirohi, 2020<br>Spinei, 2021 |
| **Red grape pomace**  | • Anthocyanins for natural colorants (extraction)<br>• Polyphenolic compounds for natural antioxidants (extraction)<br>• Proanthocyanins (tannins) for natural additives (extraction) | • Bio-chair (anaerobic pyrolysis)<br>• Pyrolysis oil (fast pyrolysis)<br>• Bio-fertilizer (fermentation) | • Animal feed<br>• Fertilizer<br>• Energy (combustion) | Giacosa, 2023<br>Sirohi, 2020 |
| **Apple pomace**  | • Polyphenolic compounds for natural antioxidants (extraction)<br>• Pectin for dietary fibers (extraction)<br>• Bio-ethanol (fermentation) | • Fruit leather, paper<br>• Bio-chair (anaerobic pyrolysis)<br>• Apple flour for food additive | • Animal feed<br>• Energy (combustion) | Costa, 2022 |
| **Olive pomace**  | • Polyphenols for natural antioxidants (extraction)<br>• Pectin for dietary fibers (extraction)<br>• Bio-fuels (fermentation) | • Bio-chair (anaerobic pyrolysis)<br>• Bio-fertilizer (fermentation) | • Animal feed<br>• Energy (combustion) | Millan-Linares, 2021<br>Podgornik, 2019<br>Riberio, 2020 |
| **Pumpkin seed cake**  | • Polyphenols, tocopherols, sterols as natural antioxidants (extraction)<br>• Amino acids for dietary supplement (extraction) | • Protein flours for functional nutrition (mill)<br>• Pumpkin seed flour for food production additive (mill) | • Animal feed | Singh, 2024 |
| **Wood bark**  | • Lignin for chemical production (extraction)<br>• Phenolic components for adhesives (extraction)<br>• Condensed tannins for polymer resins (extraction) | • Cellulose production (extraction)<br>• Bio-chair (anaerobic pyrolysis)<br>• Pyrolysis oil (fast pyrolysis) | • Energy (combustion) | Das, 2020<br>Jablonsky, 2017<br>Juvančič, 2021 |

Source of pictures: red grape pomace: https://www.academicwino.com/wp-content/uploads/2012/11/grape-pomace-The-Academic-Wino.jpg, olive pomace: https://www.zrs-kp.si/wp-content/uploads/2023/11/Moznosti_uporabe_ostankov_SPLETNA-IZDAJA.pdf, pumpkin seed cake: https://www.carphunterco.com/images/thumbnail/produkte/large/AR_25274_0.jpg; grape pomace and wood bark: free accessed on web; apple pomace: own.

The possibilities of application of by-products and residues from primary production and the agri-food processing industry as a potential source for new products were evaluated by development of value chains regarding the region potential of project partners. Slovenia have long and reach tradition of grooving fruits such as grape and apple and oily plants such as olive and oily pumpkin and processing them to wine and oil. Slovenia is also very reach in forest and therefore the wood processing industry had good background for it developed. By-products and residue of presented industries, grape and apple pomace, oil cake and pomace, wood bark and residue are not properly used jet in context of circularity and bioeconomy and there exist the potential for development of value chains with high

added value products, which were evaluated by TeBiCE project. Three key sectors were identified for evaluation by project TeBiCE:

- Fruit production and processing (grape and apple);
- Oil production and processing (olive and pumpkin seed);
- Wood processing industry, particularly timber (wood bark).

Within this framework, six value chains (VC) were developed and assessed: grape pomace VC, red grape pomace VC, apple pomace VC, olive pomace VC, pumpkin seed cake VC, and wood bark VC. Table 1 represents the potential of grape pomace (white and red), apple pomace, olive pomace, pumpkin seed cake and wood bark evaluated in TeBiCE project VCs.

By products such as grape pomace, apple pomace and olive pomace are reach source of various phenolic components and also of polysaccharides like pectin (Sirohi, 2020, Costa, 2022, Millan-Linares, 2021). Red grape pomace is rich in natural colorants, anthocyanins, those could be applied as natural colorants (Giacosa, 2023). Since grape pomace contain high amount of free accessed sugars is good source of nutrients for fermentation process for production of industrial enzymes, bio-ethanol, bio-gases, chemicals produced by fermentation process such as citric acid or bio-biased polymers such as poly-hydroxy-butyrate (Sirohi, 2020). Apple pomace is also good source for fermentation processes, especially for bio-ethanol production (Costa, 2022). All presented by-products, especially, grape pomace, apple pomace and olive pomace, are mostly used for feed production or are deposed in nature as fertilizer (Sirohi, 2020, Costa, 2022, Podgornik, 2019). By investing in application of processes such as pyrolysis and fermentation, the by-products could be processed in middle added value products such as bio-chair or bio-fertilizer were additional benefits are given by energy or bio-gas production (Sirohi, 2020, Costa, 2022). Pumpkins seed cake is residue of pumpkin oil production and contain high amount of fibers and proteins and is usually used for animal feed. Because they high nutritional value is interested also as functional food ingredient (Singh, 2024). The main by-product from timber industry (sawmills) is wood bark that contain wide range of natural component. Tannins are one of high interest because wide range of applications (Das, 2020). Wood bark is also important source of lignin and phenolic components those could be applied in production of chemicals and adhesives

(Jablonsky, 2017). Common application of wood bark is production of energy by combustion. By processing wood bark by pyrolysis bio-chair and pyrolysis oil can be produced together with energy (Juvančič, 2021).

In the follow the potential of selected by products and they producers, biomass providers, in Slovenia was evaluated by Value Chain Generator® artificial intelligence tool.

## 3 Application of Value Chain Generator® - an artificial intelligence tool

The Value Chain Generator® - an artificial intelligence tool (VCG.AI) is a smart data platform for the development of the circular industry. VCG.AI uses a modelling system to develop circular value chains that incorporate clean technologies and processes (vcg.ai, 2024). The application of VCG.AI tool in TeBiCE project was part of WP1 activities, where preliminary evaluation of bioeconomic potential of by-products and residues from primary production and the agri-food processing industry of project partners was evaluated. The evaluation was performed based on the data of small and medium-sized enterprises (SMEs) from the partner regions.

For preliminary evaluation of bioeconomic potential in Slovenia, data of SMEs from the following sectors were collected:

- Fruit production and processing (Fruit and vegetables preserving and processing),
- Wine production (Vineyard and wine production),
- Oil production (Pumpkin seed and olive oil production),
- Wood industry (Sawing, planning and impregnation of wood) and
- Production of natural extracts (production of condiments, spices, fragrances and other additives; production of essential oils; production of other chemical products).

The collected data included basic information on companies (name, location, activity, NACE code) and was collected from a free access webpage Poslovni Asistent Bizi[4] (eng. Business Assistant Bizi). Collated data was analyzed by VCG.AI, the results are presented in the following paragraph.

[4] https://www.bizi.si/

Figure 2 represents results of evaluation of collated data. Figure 2 A represents an overview of collected information of 308 SMEs from Slovenia that were included in the VCG.AI evaluation. The largest percentage of biomass providers (by-product producers) comes from the wood processing sector (sawmill and wood planning, 108), which accounts for 35.6%. This is followed by the wine production sector at 21.5% (62) and the oil and fat production sector at 21.1% (61). Figure 2 B illustrates the primary mass flows within these evaluated sectors: wood processing (sawmills), wine production (manufacturing), and oil production (oil mills). The main by-products from sawmills – woodchips (26%), bark (19%), and sawdust (8%) – constitute over half (53%) of the wood mass flows. These by-products are typically used as a significant biomass source, often for thermal energy. It could be applied also for new high-added value products. In wine production (wine manufacturing) the main by-product represents grape pomace (10 %), grape seeds (5 %), stalks (3 %) and other residue (5 %) that represents more than 23 % of all mass flows. In oil production depending on applied technologies different by-products are produced such as oil-cake or pomace. They represent around 55 % of mass flows.

Figure 2 C – E represents distribution of SMEs, by-product producers in Slovenia for evaluated sectors: wood processing, sawmills (C), wine production (D) and oil production, oil mill (E). The distribution of by-product producers shows as distribution, density of location where separate by-products is available in Slovenia. By-product producers are potential biomass providers, therefore locations with a high concentration of by-products provide a strong foundation for further evaluation and the development of value chains. Most concentrated regions of the wood processing industry (sawmills) and its by-products were in the surrounding area of cities Ljubljana, Kranj and Celje, whereas others were evenly distributed throughout Slovenia (figure 2 C). Wine production mostly concentrated around regions in the South-Western part of Slovenia surrounding the cities Koper and Nova Gorica and in the Eastern part of Slovenia (figure 2 D). The oil producers were concentrated mostly in two regions: the coastal part of Slovenia where olives are grown and processed to olive oil and in Eastern Slovenia where pumpkin seed oil is produced (figure 2 E).

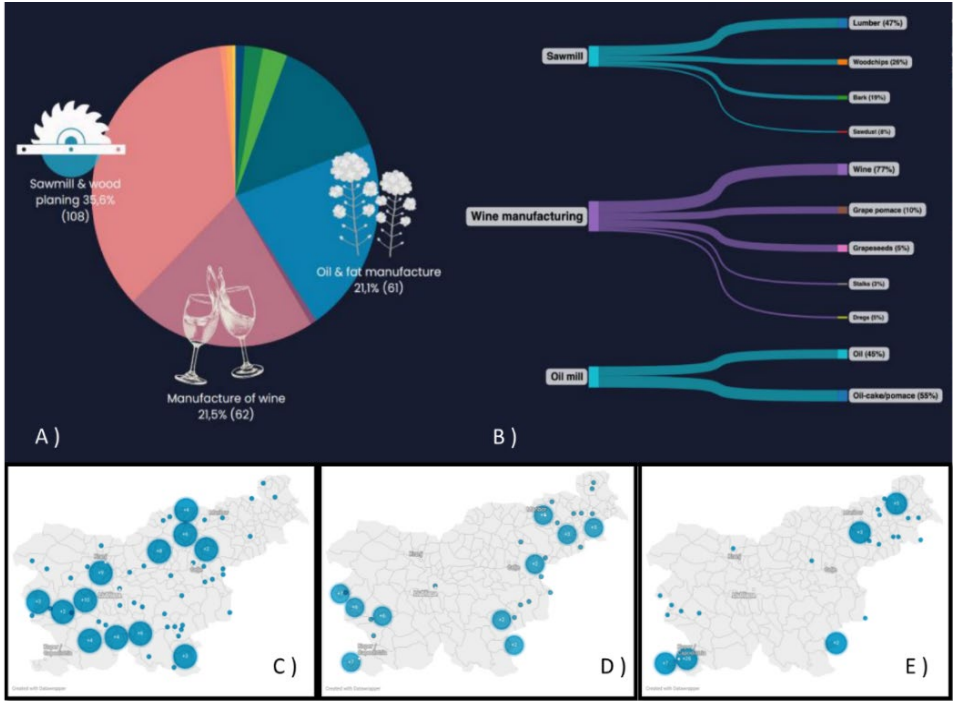


**Figure 2: Results of evaluation of collated data of SME-s in selected sectors in Slovenia: A) statistical overview of collected data; B) Mass flow overview in sawmill, wine manufacturing and oil mill; C–E) Distribution of by-product producers in Slovenia for sawmills (C), wine manufacturing (D) and oil mill (E).[5]**

[5] Internal TeBiCE project report: VCG.AI_TeBiCE_Slovenia (1)

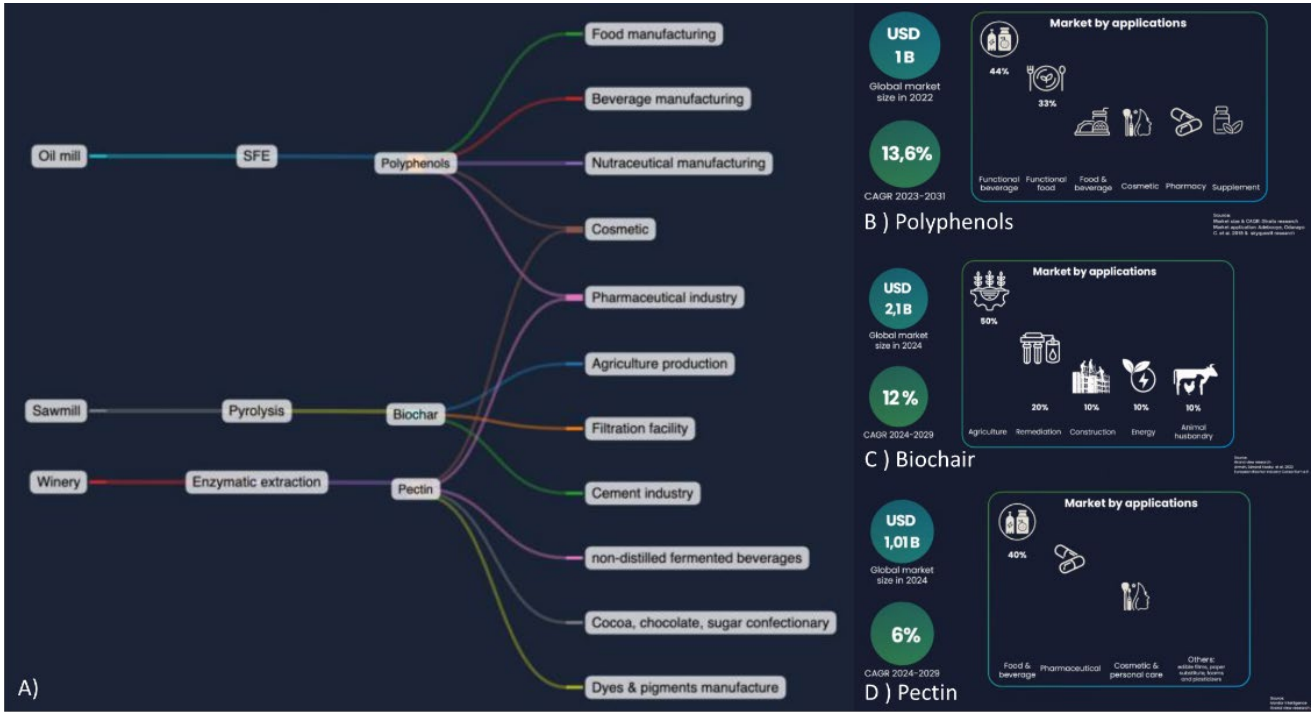


**Figure 3: High potential value chains in Slovenia generated by VCG.AI: A) Mass flow of sawmill by-product VC, wine producing by-product VC and oil production residue VC; B–D) Economical potential of VC products, polyphenols (B), biochar (C) and pectin (D).**[6]

[6] Internal TeBiCE project report: VCG.AI_TeBiCE_Slovenia (1)

By following evaluation of collected data and regarding priority stated, three value chains were outlined, where tree products polyphenols, biochar and pectin can be produced by three proper valorization technologies SFE, pyrolysis and enzymatic extraction. Figure 3 represents final VCG.AI generated VCs (A), together with economical potential of products (B – polyphenols, C – biochar and D – pectin). In the follow detailed evaluation of each product was performed.

Polyphenols in Slovenia could be produced from all tree biomass providers using SFE technology and can be applied as natural food preservatives or as active ingredients of functional beverage, nutraceuticals, cosmetics, pharmaceutics. In Slovenia pectin could be produced form wine and oil production residue by enzymatic extraction and applied as gelling agent in food industry, stabilizer in some beverage and cosmetics and as drug delivery in pharmaceuticals. Biochar can be produced from wood and oil production residue by pyrolysis. Its main application is as soil amendment in agriculture, as pollutant adsorbent and as additive in cement industry.

For all three product the market insight was prepared to light out the global market possibilities (Figure 3 B – D). The bigger Global Market size in 2024, with 2,1 B USA, was evaluated for biochar, followed by pectin with 1,01 B USD and polyphenols with 1 B USD in 2022. The bigger market growth in years 2024 – 2029 was predicted for polyphenols with more than 13 %, following by biochar (12 %) and pectin (6 %). Biochar and polyphenols have a better economical prediction and a broad spectrum of potential uses in comparison to pectin those is mostly applied in food application. Therefor biochar and polyphenols have high potential for exploiting by-products of evaluated sectors in Slovenia.

## 3 Conclusions

The potential of by-products and residue from three sectors in Slovenia, fruit production and processing, oil production, and wood processing industry, were evaluated in the framework of TeBiCE project by application of Value Chain Generator® artificial intelligence tool. Three value chains were outlined, where three products polyphenols, biochar and pectin can be produced by three valorization technologies SFE, pyrolysis and enzymatic extraction. For all three products the market overview was performed. Biochar and polyphenols have a better economical

prediction and a broad spectrum of potential application regarding to pectin and therefore are products with high potential for exploiting by-products biomass in Slovenia. VCG.AI tool was shown as applicable tool for fast and good evaluation of by-products potential for development of value chains in the context of circular bioeconomy.

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