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Rural regions as key locations for the Circular Bioeconomy: insights from the northern interior of Portugal

Ana Sofia Brandão*[a], José M. R. C. A. Santos[a]

[a] Centro de Investigação de Montanha (CIMO), Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253 Bragança, Portugal.

* Corresponding author E-mail: anastbrandao@ipb.pt

Abstract

Rural areas have often been singled out as strategic locations for the implementation of the Circular Bioeconomy (CBE) concept. This study aims to carry out a detailed analysis of the northern interior of Portugal, focusing on its business dynamics within the CBE. Two representative case studies were selected and critically compared with successful cases from European Nordic countries. The results showed that, generally, waste is managed inefficiently and with little benefit. The cross-comparison with the Nordic CBE model revealed that there is a lack of synergies and collaboration between different stakeholders, from the most basic to the most advanced level. Also, investment in more applied education, as well as a culture based on trust and dialogue, would greatly contribute to the successful implementation of regional CBE policies. In short, innovation, not only in products and services, but mainly in partnerships is key to a sustainable economic growth in rural regions.

Keywords: rural regions, local development, sustainable innovation, circular bioeconomy, industrial synergies.

1. Introduction

The pressure on exploitation of natural resources as a result of the exponential increase in the world population, as well as the respective effect on climate change, are latent threats to sustainable economic growth. Conversely, rural development is key when it comes to fighting hunger, poverty and global warming, so it should be at the heart of governmental policies (Mantell and Van Hove, 2008).

A powerful tool that can enhance the development of sustainable products and processes is the Circular Bioeconomy (CBE) concept (Kardung et al., 2021; Muizniece et al., 2019), that allows to maintain the balance between economic productivity and conservation of natural resources. This is a transdisciplinary concept, arising from the intersection of bioeconomy, which encompasses the production of renewable biological resources and their conversion into value-added products, and circular economy, which aims to strengthen the paradigm shift from the current linear economic model to a circular one that keeps resources within the value chain for as long as possible (Carus and Dammer, 2018). Impacts on the economy and environmental pressures are notable with the adoption of circular economy measures, namely the overall material extraction is reduced by around 10%, while the impact on employment is small but positive (Wiebe et al., 2019). In brief, the CBE is focusing on providing alternative business models to invest in the transition to a circular economy powered by renewable energy (Brandão et al., 2021). The role of CBE in innovation for a sustainable economy has not only been recognised but the concept itself has become part of the core strategy of the European Green Deal to lead Europe towards a process of combating social, economic and territorial inequalities with the aim of promoting a harmonious and sustainable development of the EU as a whole. This strategy also includes the concern that rural areas are not left behind in this transition mechanism, enabling digital innovation and fixing rural entrepreneurship, and young people in depressed rural areas (European Commission, 2019a). In fact, there are mutual benefits when both, rural regions and CBE, are aligned. Rural areas are considered to hold great potential for the implementation of the CBE concept (Matiuti et al., 2017). The food industry, agriculture, forestry and fisheries, are the principal driving forces of the rural economy. These activities generate huge amounts of waste streams, which in turn provide an opportunity for the establishment of local bio-industries powered by this biomass. On the other hand, CBE acts as an engine of rural development through intensive use of knowledge about resources, processes, technologies and biological principles for the sustainable production of goods and services in all sectors of the economy (Brandão et al., 2021). This approach strongly promotes the creation of industrial symbioses, where waste and/or by-products can be transformed into raw materials for other products, thus avoiding large quantities of waste ending up in landfills and, simultaneously, promoting their valorization (Neves et al., 2019). As a result, new opportunities for job creation in new bio-based value chains arise (Refsgaard et al., 2021), which also reduce depopulation of rural areas.

In Europe, increasing efforts have been made to promote new activities linked to CBE at the transnational, national, and regional level (Bio-based Industries Consortium, 2020). Focusing on the northern interior regions of Portugal, namely on “Terras de Trás-os-Montes” and “Douro”, and although they have several geographical and social characteristics that place them at an economic disadvantage, such as difficult accessibility and human out-migration, their predominant economic activities as agriculture, food industry and forestry, comprise a valuable asset in the scope of CBE (Douro Intermunicipal Community, 2015; Intermunicipal Community, 2021). Geographically, these territories are cross-border regions, with the north and east being bounded by Spain, in particular by the province of "Castilla y Léon", which is also an added-value in terms of promoting cooperation between the two regions. Still, these areas are far from becoming models of CBE, whereas Nordic countries, with analogous regions, are heading all the world rankings of achievements in generating a prosperous and innovative economy with nature being at the centre of their economic model (Refsgaard et al., 2021). According to the last United Nations Sustainable Development report, countries such as Finland, Sweden and Denmark complete the podium of countries, worldwide, that are closest to achieving all 17 Sustainable Development Goals (SDGs) approved by the UN General Assembly in 2015 (Sustainable Development Report, 2021). The Environmental Performance Index, an initiative of Yale and Columbia Universities, two of the most prestigious universities in the USA, gives Denmark the first place (Environmental Performance Index, 2020). The Good Country Index, that assess whether a country is a creditor or a burden to the planet, gives the podium to Sweden, followed by Denmark, with other Nordic countries in the top 10 (The Good Country Index, 2021). Sweden also tops the sustainability ranking of Robeco, one of Europe's largest asset managers. Once again, countries such as Finland, Norway, Denmark, or Iceland feature in the top 10 (Robeco, 2021). Documenting and analysing this phenomenon is particularly important, as this will allow us to understand what needs to be done in the inland territories of Portugal to make them evolve towards the successful Nordic CBE model. However, empirical research on the characteristics of these territories that allows for an assessment of its specific potential, within the scope of the CBE and contribute to the Sustainable Development Goals of the UN 2030 Agenda, remains scarce.

In face of the above, the research questions forming the basis of this study are the following:

1) What are the companies and actors in the regions of Terras de Trás-os-Montes and Douro, as well as the associated resources, activities, products and processes with potential development in the field of CBE? We answered this question by gathering information about the industrial and business fabric of these regions, as well as by analysing interview data from selected small and medium-sized enterprises (SMEs).
2) How do similar regions in the Nordic model successfully apply CBE concepts to their business models and what types of stakeholders act and collaborate in order to achieve a sustainable regional development in their territories? We answer this question by investigating CBE examples on how they are organised and contribute to regional development, namely selected green-growth Nordic cases.
3) Finally, we reflect on what are the key barriers to sustainable development in order to be able to unlock the potential of rural areas to implement CBE principles in the northern interior of Portugal.

The remaining of the article is structured as depicted in Fig 1.

2. Materials and methods

The research methodology used consists of a mixed methods approach, comprising information gathering (secondary sources), a survey, semi-structured interviews, and the use of case studies. All the phases of the study were exploratory in nature and are detailed next. Fig. 1 describes the filtering process applied in the selection of relevant companies and of the case studies to be addressed in detail.

2.1 Information gathering

This phase included identifying and analysing companies and agents in the region under study, as well as the resources, activities, products, and processes associated with potential development in the CBE field. The identification of companies was carried out based on general information, such as address, economic activity, sector, tax identification number, responsible persons and managers, as well as contacts, obtained through online searches on websites containing information on companies in Portugal, such as Racius, Portugalio, Einforma, Ciberforma and Inforempresas. The companies considered relevant to the study were those whose activity fits into the agrifood and/or forestry sector. In addition, the specific flow of biological waste and its possible value chains were characterized, as well as the potential for replacing critical raw materials with bio-based products.

2.2 Survey and interviews with companies and agents

Given the contemporary nature of the phenomena under study, we conducted a survey and semi-structured interviews to record the knowledge and experience of relevant informants. Between November 2019 and February 2020, 15 companies agreed to participate in the study. The questionnaire design was based on the development of the bioeconomy offer and the promotion of new markets demand. It was divided in two main parts: i) questions concerned with the company's background information and ii) the familiarity with the CBE concept and practices. Interviews were conducted in Portuguese, face-to-face or by phone, and involved owners or managers responsible for the company strategy or corporate sustainability (Table 1). They served to deepen details and to clarify information collected in the survey. Often, the questionnaire was completed in the interview itself. Anonymity was guaranteed to the interviewees and the company they work for.

2.3 Analysis of information and exploration of two case studies

The information collected in the previous steps was triangulated and compared with each other. Next, two case studies were selected considering their potential economic importance and transferability, to illustrate benefits from applying the CBE concepts *in loco*.

3. Results and Discussion

3.1 Identification and analysis of companies and resources associated with development potential within the scope of CBE

The exhaustive search of companies, based in the regions under study with potential for implementing development policies within the scope of CBE, recorded a total of 280 possible targets. This figure involves businesses operating in key sectors (agriculture, food industry and forestry). However, after a deeper analysis, this number was reduced to 31 companies that matched the inclusion criteria, namely:

- Relevance of the main activity for local economies;
- Significant volume of waste generated;
- Relevance and applicability of waste within the scope of the CBE.

In the food industry sector, stand out activities related to the production of sausages, dried fruit trade, fruit trade, especially apples, the production of milk and dairy products, with special emphasis on cheese, and bread making. In the agriculture sector, activities related to the production of olive oil, wine, mushrooms, nuts, apples, vegetables, roots and tubers stand out. In the forestry sector, the most important activities are those related to forest exploitation, as well as maintenance and cleaning of urban green spaces. From the aforementioned areas of activity, we selected the six with the greatest economic relevance for the region, which additionally have great potential within the scope of the CBE concept: dried fruits, apples, sausages, wine and mushroom production, and forestry. Thus, the 15 companies interviewed constitute a representative sample of these areas. Table 1 gathers key information on these SMEs.

In regions whose main economic activity is the primary sector, the usual practice is the use of this waste for the production of compost for soil fertilisation or as a source of animal feed. Although some of the CEOs revealed that they were aware, even if only to a limited extent, of practices related to the CBE, most were not aware of the concept at all. The CBE, covering all sectors and systems that depend on biological resources, is one of the largest and most important economic areas in the EU, with an annual turnover close to 2 billion euros, and employing around 18 million people (European Commission, 2019b). Since it encompasses areas such as agriculture, forestry, and fisheries, it is an essential domain to boost growth in rural and coastal regions. In what concerns rural regions in particular, this domain is of high importance, since they rely essentially on a productive matrix based on the exploitation of natural resources, leading to economic specialization in activities related to agroforestry and agro-industrial activities.

Another expected finding is that the vast majority of the business fabric is composed of micro enterprises, typically with less than 10 employees and often family-owned. These territories show a typical behaviour of an underdeveloped region, with significant prevalence of the primary sector. The industrial sector has a weak implantation, with low level of internationalization, as so does the information and communication technology sector, which is also underexplored, hindering regional development. Furthermore, the low population density and the growing aging population inhibit the capture of business investments and, consequently, economic innovation (Carvalho, 2018).

Both aspects, lack of knowledge combined with small size and corporate culture, can be a significant obstacle to the regional competitiveness.

3.2 Characterization of the specific flow of biological wastes, its possible value chains, and the potential for replacing critical raw materials with bio-based products

As a result of the individual analysis of the range of companies previously selected, namely with regard to the nature of the generated waste and by-products, it was possible to identify several flows of biological waste in the set of the three most relevant industrial sectors. In the food industry sector, nine streams of biological waste were identified, and in the agriculture sector, six streams of biological waste were identified. In the forestry sector one flow of biological waste was identified, which results from the combination of all residues from activities such as pruning and cleaning of forests and other green spaces, essentially resulting in plant remains such as branches, twigs and leaves. This information is detailed in Table 2.

Despite the reality mentioned above, and according to our results, regions like Trás-os-Montes and Douro have an enormous untapped economic potential, which creates opportunities in diverse areas, such as those based on the biorefinery concept. In addition, according to official governmental information (National Official Journal, 2020), Portugal is one of the European countries with the greatest potential to carry out CBE policies, and it is estimated that this represents around 43 billion euros of yearly turnover and 320 thousand jobs at national level. The agrifood, agricultural and forestry sectors have been among the key sectors of the national economy. The large number of by-products and waste resulting from these activities constitutes a potential source of biomass raw material, contributing positively to the development of innovative products and industrial processes, and creating jobs at the local level. For example, in Portugal, total food losses and waste amount to 1 million tonnes (17% of the annual production) (The Northern Regional Agenda, 2019), while the total amount of agricultural waste reaches 1 456 000 ton/year. More than 50% of the agriculture value in Portugal comes from fruit and vegetable production, and 41.2% from animal production, in which milk production accounts for 25% (GPP, 2019). Forests, on the other hand, represent 36% of the mainland territory's land use, being mainly concentrated in the interior of the North and Centre of Portugal (Institute for Nature Conservation and Forests, 2019). The high economic value of the forest space is reflected by its multifunctionality, both in its commercial dimension, in the environmental services it provides, and in the enhancement of the landscape and its recreational function.

All of these key economic activities and their respective waste streams, frame the characteristic economic structure of the regions of Terras de Trás-os-Montes and Douro, allowing us to affirm that these regions are a "diamond in the rough", as we will continue to demonstrate later in this study.

3.3 Case study approach

In order to illustrate the potential of CBE in the regions under study, two case studies have been selected that aim to provide an understanding of the opportunities that CBE has to offer the business sector. The first case study will focus on apple production, while the second will focus on the forestry sector. The choice of these two examples was strategic. While apples are one of the most widely cultivated fruits in the world, with a production of around 87 million tonnes in 2019 (FAOSTAT, 2019), forests have gained prominence as the most important terrestrial biological infrastructure in Europe, as well as the largest source of renewable resources in the origin of various goods and services (Hetemäki et al., 2017). Thus, besides being sectors of great economic importance for the regions under study, both cases studies present an enormous potential for transferability to any other region, at the national and/or international level.

3.3.1 Apple production

Currently, apple is a brand image of one of the municipalities of Terras de Tás-os-Montes, with about 800 hectares and an annual turnover of around five million euros. In this context, the largest fruit trading company in the region handles around 4600 tons of apples per year, sold fresh mainly for the national and Spanish markets. The Golden cultivar is the most widely grown in the region, occupying most of the 250 hectares of the company's associated orchards. During the harvesting season, the company produces up to 1500 kg of apples per month. With regard to the greatest difficulties the company faces in this market, the weather conditions assume the role of greatest "competitor" that is often responsible for several crop losses. Furthermore, around 10% of its fruit is wasted, despite being tasty and of high quality, because it does not always have the perfect appearance in terms of colour, shape and calibre that large distribution agents demand and that consumers choose. Based on this waste, the company tested the feasibility of a new economic activity, namely the production of cider, but most of it is still sold to processing industries for the preparation of juices, jams and other concentrates, at around € 0.10/kg. The low price at which apples are sold to this type of industry creates serious imbalances between the actors involved, as the profits end up tending mainly to one party. In terms of composition, apple pomace consists mainly of peel and pulp (95%), seeds (2% to 4%) and stalks (1%) (Barreira et al., 2019), and represents a serious environmental problem when disposed of without adequate processing. The chemical and nutritional characterisation carried out in various scientific studies reveal a significant amount of nutrients that depend on the apple variety, origin and processing technology involved (Perussello et al., 2017). Thus, the disposal of this type of waste/by-product becomes a significant waste of resources. Traditionally, apple pomace is used as raw feed for livestock. However, this biomass is a rich source of compounds with interest for human nutrition. Thus, identifying ways to incorporate apple processing by-products as a food ingredient into the human diet can provide many health benefits. In addition, given the large volume of apple pomace generated each day and its richness in compounds that can be extracted with high added value (*cf.* Fig. 2), the non-use of this residue constitutes a real economic loss for the apple industry. For example, apple flour is a new food ingredient whose incorporation has been tested in some recipes, among which cakes (Masoodi et al., 2002). Functional and dietetic foods have experienced a growing consumer demand and these flours present nutritional benefits, such as dietary fibre, vitamins, minerals and phenolic compounds (Rupasinghe et al., 2009). Besides, apple pomace is already one of the raw materials with the greatest potential for pectin extraction (Canteri-Schemin et al., 2005; Yates et al., 2017). Pectins constitute a group of substances with expressive interest for the food industry. In the last decades, these compounds have been used essentially in powder form due to their capacity to act as a gelling agent, mainly in the elaboration of jellies, fruit jams, pastry and juices (May, 1990). Additionally, due to several technical and health-related functions of pectin, some products have been designed and marketed progressively, namely in the medicine and radioprotection sectors and for alleviation of constipation symptoms (Moslemi, 2021). The production of citric acid from apple pomace by solid-state fermentation using commercial strains of fungi (*Aspergillus niger*) has also been widely investigated (Dhillon et al., 2011). Citric acid is an organic acid used in a wide range of applications, including medicines, flavouring extracts, food, beverages and sweets, as well as in the manufacture of paints and dyes (Amato et al., 2020). Innovative and environmentally friendly materials are also increasingly being developed by several brands. The goal is to promote the circular economy by incorporating raw materials, that are considered waste by other industries, into their products. This form of more conscious consumption of fashion items, known as slow fashion, has found more and more supporters and makes room for brands that promote a more sustainable lifestyle and bet on the quality of materials and manufacturing. Examples of this are brands such as the Portuguese Verney (https://verneystore.com) and the Italian Happy Genie (https://happy-genie.com), which use apple waste as raw material for the production of shoes and bags, respectively.

3.3.2 Forestry

In general, companies in the forestry sector from these regions have as their main activity not only services related to logging, but also the cleaning and maintenance of gardens and roads. In this particular case study, the company's main products/services are grouped by i) the forestry area, consisting of planting and felling trees, ii) the gardening area, maintenance and installation of irrigation systems and iii) the area of roads deforestation and cleaning. The main customers are road infrastructures, municipalities and other public institutions, as well as individuals. In terms of turnover, it operates between 500,000 - 600,000 €/year, of which 200,000 € correspond to the forest area, 120,000 € correspond to gardens the area and 200,000 € correspond to the roads area (approximate figures). Its activity essentially results in lignified waste, such as wood from the management of woods and forests, and less lignified waste, consisting of pruning branches and foliage, which result from both forest cleaning and the maintenance of gardens and roads. The less lignified residues are composted and further used as fertilizer. In the case of the forest maintenance, all the branches removed from the trees are usually left on the ground, constituting a very high organic load for the respective locations. In order to carry out an adequate fragmentation of the residues by means of volume reduction, the company acquired a woodchipper machine. This facilitates not only the biodegradation of waste, but also its incorporation into the soil. The idea would also be the subsequent acquisition of a pellet press that would allow the residual forest biomass to be compacted, so as to guarantee the flow of the product and its integration with industrial value in the energy-consuming units. However, the cost of waste collecting and transportation made the idea unviable, which in fact has been a major obstacle in the biomass valorization in the forestry sector in Portugal.

Regardless of this limiting factor, lignocellulosic biomass is a potential substitute for fossil fuel as it could be transformed to various bio-energy and bio-based products by biorefineries (Ong and Wu, 2020). It is estimated that every year, in Portugal, around 6.5 million tons of forest waste is produced, of which 2.2 million tons can be processed. Indeed, this waste is a potential alternative to the traditional energy model, both because of its guaranteed availability and its lower environmental impact. In addition, there is another extremely important factor, namely that of significantly reducing the thermal load of forest stands, reducing the risk of fire. In this sense, the burning of forest biomass for energy purposes has been the most addressed promising response. In Portugal, as a result of forestry and energy policies, as well as of the promotion of the bio-economy and circular economy paradigms, we have been witnessing a greater incentive for the use of forest biomass. For example, the National Strategy for Forests (Portuguese Republic, 2015) encourages a greater use of surplus products from forest exploitation and other types of biomass which are currently seldom used. Also, energy legislation such as the National Energy and Climate Plan 2021-2030 (Portuguese Republic, 2020), encourages the increase of energy sources from forestry, agriculture and waste, along with other renewable energy sources, in order to achieve the target of 47% share of renewable energy in gross final consumption by 2030. However, the availability of forest biomass is temporally and geographically fragmented, which makes its valorization particularly challenging, being imperative to find cost-effective solutions for biomass production, storage and transportation up to the processing facility (Fig. 3).

Currently, this is an area of multidisciplinary international research in which methodologies and tools have been developed to support the planning of operations and generate scenarios to analyse different investment options. For example, Marques et al. 2018 propose a Mixed Integer Programming (MIP) for tactical decisions related to the optimal allocation of wood chips from forest residues on forest sites to terminals and power plants, considering the impact of its energy content variation. The approach was applied in a biomass supply chain case in Finland, and results suggested a 20% improvement in the supplier profit when compared with a baseline situation that relies on empirical estimates for a fixed and known moisture content at the end of an obliged storage period. More recently, Falcone et al. 2020 draws potential new strategies for an effective forest sector's transition towards a circular bioeconomy in Italy. The results show that besides improving environmental and forest planning tools by defining viable methods of circular management, other effective strategies are: i) promoting investment in forest infrastructure, ii) supporting entrepreneurship programs for forest professionals; and iii) enhancing innovative forest-based value chains.

The establishment of small plants to produce heat or heat and electricity has been the model advocated to boost the local economy in the regions under study, help to clean up the forest and create wealth. Besides, this is also a successful model in the Nordic countries, characterised by greater efficiency and minimisation of waste. However, other strategies have been employed to recover value added products, namely non-energy based biorefineries. In these cases, the aim is to obtain bioproducts and biomaterials from biomass, with only its non-added value fractions being used for energy purposes (Brandão et al., 2021). The biomass-derived products to be obtained may be chemically equivalent to existing petrochemical products, with the market already assured as an alternative for these ("drop in") or may have a new functionality and therefore a slower market penetration.

In this sense, and based on the CBE concept, a clear definition of what is forest biomass and its residues is fundamental to develop efficient regulatory frameworks for its management, similar to what exists for some specific waste streams, such as glass, plastics, tyres or waste oils. For such sectors, specific regulatory frameworks exist that assign responsibility to the product producer for managing the life cycle stage of products when they reach their end of life and become waste. For example, the Ecovalor concept currently implemented in Portugal is the fee that must be paid by each tyre introduced into the national market. This value is collected by tyre producers and finance a waste management entity that collectively assumes this responsibility (Valorpneu). The Ecovalor must be passed on in the commercialisation chain up to the end consumer when the tyres or the vehicles/equipment containing them are sold. Thus, analogously, a possible strategy in the scope of forest biomass and its residues could involve financing a management process through a fee collection system. By way of illustration, when a carpenter buys wood from a logger, he/she could pay a fee for the management of forest waste by a dedicated entity.

3.4 Success examples in the European Nordic regions

There seems to be a consensus that the Nordic countries are an example to the rest of the world of how a prosperous, innovative economy can be generated in harmony with nature. According to H.G. Kristinsson, chair of the Nordic Bioeconomy Panel, the Nordic countries "are strongly placed to be global leaders in the production and utilisation of bio-resources that will enhance both competitiveness and sustainability"

(Nordic Council of Ministers, 2017). Nordic co-operation is one of the world's most extensive forms of regional collaboration, involving Denmark, Finland, Iceland, Norway, Sweden, Faroe Islands, Greenland, and Åland Islands (Nordic Co-operation, 2016). The Nordic Bioeconomy Panel, initiated by the Icelandic Presidency Programme for the Nordic Council of Ministers with the aim to make a proposal for a Nordic Bioeconomy strategy, contributes strongly to this recognition. This resulted in a catalogue of 25 cases, as exemplary models of Nordic solutions to global challenges, focusing on four pillars, namely replace, upgrade, circulate, and collaborate (Nordic Council of Ministers, 2017). In this context, there are several bioeconomy cases in the Nordic region focusing on circularity and contributing to the circular economy in different ways (Refsgaard et al., 2021). A large part of these examples stem from the drive for rural development which has played a prominent role in Nordic policies. The definition of rurality is not generalized, varying between countries and even within countries. In a European context, the OECD (Organisation for Economic Co-operation and Development) approach has been widely adopted, identifying three classes of regions, namely (Nordregio, 2011):

- Predominantly urban < 15% population in rural communities;
- Significantly rural, 15 – 45% population in rural communities;
- Predominantly rural > 50% population in rural communities.

Thus, we highlighted initiatives that are taking place in predominantly rural regions, with low population density and considerable distance or accessibility to urban centres. Furthermore, these are regions covered with a large area of forest, with prominence of the primary sector as the main economic activity, resulting in a large availability of biomass. It should be noted that, in general small businesses predominate, with the majority of companies being small and medium-sized enterprises (SMEs) (D'Amato et al., 2020). Both locations - the rural areas of the Nordic countries and the regions under study - share these characteristics. Thus, the former could stand out as inspiring examples and offer innovative ideas towards rural development in Terras de Trás-os-Montes and Douro. In this sense, we have analysed two innovative Nordic (circular) bioeconomy cases that present solutions for global challenges, representing a strong basis for the sustainable inclusive strategies of the area they are embedded in and for regional development in a wider sense.

3.4.1 Porvaldseyri | Iceland

Porvaldseyri is a cereal and dairy farm situated on the south coast of Iceland. The conditions at Porvaldseyri are special and have already been placed far towards sustainability. This is because many resources and energy are produced on the farm from products and co-products of its milk and grain production, aiming to become a self-sufficient and sustainable farm that adheres to circular economy principles. All the farm's energy needs are covered by renewable hydropower supplied by a hydropower plant located nearby and the national grid. The energy can be used for drying grain, dairy production, which is the farm's main activity, and domestic heating. Feed for livestock is almost entirely produced on the farm, namely hay, grain and rapeseed products. Rapeseed can provide biodiesel, used in tractors and other vehicles, and cooking oil. All manure from the farm is used on arable land, thus reducing the need for synthetic fertilisers (Smárason, 2016). In this way, besides avoiding buying fertiliser or grain for feed, the farm reduces costs and cuts CO_2 emissions by more than 18 tonnes per year. In addition, local bakeries and breweries that formerly had to import grain buy it from the farm. Last but not least, given its privileged location – just below Eyjafjallajökull Glacier Volcano, the farm has created a new business model innovation based on a visitors' centre at the foot of the volcano, resulting on an extra source of income. In this way, it has enabled Þorvaldseyri to exploit new synergies between the bioeconomy and tourism based on food products perceived to be uniquely Icelandic (Nordic Council of Ministers, 2017).

3.4.2 North Karelia - Bioeconomy in Europe's forest region | Finland

North Karelia is a forerunner in smart forest bioeconomy. About 89% of the total land area is covered by forests. This makes the strong and dynamic forest cluster the cornerstone of business life and industry sector of the region, which is locally owned by co-operative private firms, individuals, and municipalities. As a result, North Karelia has created a key European hub in forest research and expertise, with over 600 experts in different research organizations, businesses as well as regional development companies and authorities such as the Regional Council of North Karelia. Together, they perform internationally recognised research on potential uses of forests, educating forestry specialists at all levels, from tree harvesters to PhDs in Forest Sciences. It is a strategic work in close collaboration with local actors, forest owners, companies and citizens. They also develop innovative forestry businesses and promote the sustainable use of their forest resources - from nanoscale materials to high-rise wooden buildings. Local universities and research institutions are strongly linked with businesses through regional innovation networks. For example, Karelia University of Applied Sciences trains wood construction engineers and promotes applied research and development in the field of wood structure technology, while companies utilise Karelia's test lab in their product development. The expertise cluster in Joensuu, the region's capital, is home to the world's leading business cluster in forest machine production, being pioneers in digital forest inventory and high-rise wooden buildings. In fact, their wood construction landmarks attract visitors, businesses, investments, and industry experts from around the world. Other strengths of the region include, for instance, forest technology industries, biorefineries and renewable energy production units (Paula, 2020).

3.5 Cross-case comparison between Terras de Trás-os-Montes and Douro and the European Nordic regions

According to the Business Council for Sustainable Development, four essential steps are required for the engagement of regional companies in the CBE, namely: i) identify suitable processes and products, ii) assess sustainability trade-offs, iii) collaborate and find partners to transform waste streams into value streams and iv) innovate the product portfolio with clear business cases that pave the way for more disruptive business models that integrate its customers into the CBE (Business Council for Sustainable Development (BCSD) Portugal, 2021). The selected European Nordic case studies illustrate very well the importance of these steps as well as of the decisive role of science in regional development, since it may be an enabler for innovation and technology to boost the environmental and social sustainable economic growth, particularly in rural areas. Two main features of the Nordic success model stand out: a) the high levels of cooperation of different types of partners and b) the assemblage of interests of local and/or regional companies and public sector actors.

The Nordic case studies provide a great insight into how important the regional and local levels are in creating new institutional structures for cooperation between firms and public authorities that pave the way for successful synergistic clusters. In addition to the range of environmental benefits, such clusters allow creating significant local added value and jobs. In fact, the newly developing bio- and circular economy has experienced a growth in employment of 5–15 % or more in many Nordic regions, especially in Iceland, Denmark and Sweden (Refsgaard et al., 2021). This is also an important issue in rural regions, namely in Trás-os-Montes and Douro, where the lack of job opportunities makes young people leave the regions, contributing to their human desertification.

Also, it is clear from the two Nordic case studies explored that there is a lack of synergies between actors in the region under study. This deficit exists at the most basic level, such as in the exchange of services/products between enterprises, as illustrated in the case study of Þorvaldseyri farm with local bakeries and breweries. In this case study, it is clear the alignment of interests between local actors who collaborate not only for the sake of their own businesses but also for the recognition of the region itself through the promotion of their products. These types of synergies are relatively simple to create, provided that the business fabric is aligned with this strategy. As an example, the apple surplus in the regions of Trás-os-Montes and Douro could be valorised by pastry and bakery companies that could incorporate it in gastronomic recipes and promote it in the form of an original local product.

A more advanced level is that of the synergies created in the forestry sector in North Karelia. Mimicking this model in the forestry sector in the region under study is a major challenge, since it involves a large network of partnerships with different types of actors. Here, and taking into account the cross-border location of the region under study, the key to success would be to extend the partnerships to the neighbouring Spanish regions. This is a development paradigm that is under-exploited in Portugal. Conversely, in most European cross-border regions, high levels of development are associated with cross-border cooperation.

By trying to emulate such an efficient sustainability model as the Nordic one, several challenges are faced, especially when compared with Portugal, which is so geographically and socially distinct. The top-ranked countries (as documented in previous sections of this article) have in common the adoption of long-term commitments and carefully designed programmes to protect public health, preserve natural resources and reduce greenhouse gas emissions. Despite differences in vegetation, climatic condition and Natural resources, such policies are easily adaptable, so Portugal has also been establishing priorities and creating official documents in this sense, as for example the document "Leading the transition: Action Plan for the Circular Economy in Portugal 2017-2020" (Portuguese Republic, 2017).

However, more prevalent than the differences mentioned above are the differences in National Innovation Systems. The Nordic countries have very similar National Innovation Systems, formed by the tripod: Public Authorities, specialized economy and education. In this sense, the public authorities (namely central Governments) encourage research related to technological innovations not to be restricted to the academic level, but to be disseminated among industrial sectors, and promoting the internationalisation of the most competitive sectors. In addition, many academics work in the private sector, developing their research with funding from companies, being yet another way that the Government has found to disseminate the knowledge acquired beyond the educational field.

On the other hand, the Nordic countries make very good use of their natural resources to advance in CBE related sectors. That is, they start focusing on sectors in which natural resources provided a competitive advantage. For example, in North Karelia, construction wood is a natural continuation in the local long tradition of wood processing, which means an abundance of highly skilled professionals in the wood products and wood construction industries (Paula, 2020). This strong link with wood as a raw material and, consequently, with wooden constructions, makes this a priority topic in this region. In Portugal, the construction sector is not so closely linked to forestry, so the biggest priority, as far as its by-products is concerned, has been to produce compost or energy, which falls far short of the potential that could really be drawn from this type of biomass. To keep up with the pace of development of the other European countries, the Nordic countries promoted catching-up to boost technological development from sectors that had pre-existing competitive advantage. This also results in a heavily mechanised and digitalised forestry sector, which is another major difference between North Karelia and the regions under study. The world largest forestry machine factory is located in Joensuu. The region has a varied industry related to the forest bioeconomy, wood processing and forestry. Many companies are global market leaders in their own field, or important technology pioneers (Business Joensuu, 2021).

The awareness that education plays a fundamental role in the development of a country is also one of the defining characteristics of Nordic culture. Measures such as free compulsory elementary education and the regional dissemination of universities were essential for the promotion of research and innovation in these countries. Through partnerships with the private sector there was significant investment in these institutions, which in return disseminated their knowledge to the public and private sectors. Another characteristic of the educational system is the presence of specialised faculties. The Natural Resource Institute Finland is a good example, which studies the "superpowers" of wood in construction: its long-term durability, environmental benefits, effects on indoor air quality and side stream materials for further refinement (Luke, 2021). Also, the only cluster of forestry training covering all levels of education is located in Joensuu and offers renowned international education in the sector (Business Joensuu, 2021). Children, since primary schools, are instigated to be innovative and develop entrepreneurship, which according to the Nordic countries, is essential to build a more dynamic business culture. They believe that investing in children's education is the foundation for the creation of companies with high innovative value, as it is they who will develop projects and create the companies of the future.

Last but not least, the reason for the success of this type of clusters is also very much related to the human factor in the Nordic countries, recognised as cultures based on trust, dialogue between all levels and a human approach in bringing a new paradigm into existence and having the courage to support it (Refsgaard et al., 2021). Thus, and according to the results of our research, we conclude that the challenges in trying to emulate the Nordic model of success will go far beyond adapting policies to geographical differences, but above all to society at large.

4. Conclusions

This article presents an exploratory assessment of rural region's potential for the implementation of CBE policies in the northern interior of Portugal.

The information gathered allows us to conclude that it is not a lack of opportunities that is holding Terras de Trás-os-Montes and Douro back, but rather the lack of adequate policies, strategies and societal mobilization to make them happen. Thus, adequate national, regional and local policy instruments are needed, both to stimulate institutional structures that promote the transition to a society powered by renewable assets, and to ensure that the economic benefits of these developments are shared fairly across all the societal dimensions.

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References

Amato, A., Becci, A., Beolchini, F., 2020. Citric acid bioproduction: the technological innovation change. Crit. Rev. Biotechnol. 40, 199–212. https://doi.org/https://doi.org/10.1080/07388551.2019.1709799

Barreira, J.C.M., Arraibi, A.A., Ferreira, I.C.F.R., 2019. Bioactive and functional compounds in apple pomace from juice and cider manufacturing : Potential use in dermal formulations. Trends Food Sci. Technol. 90, 76–87. https://doi.org/10.1016/j.tifs.2019.05.014

Bio-based Industries Consortium, 2020. Annual report. Available at https://biconsortium.eu/sites/biconsortium.eu/files/downloads/BIC%20Annual%20Report%202020.pdf.

Brandão, A.S., Gonçalves, A., Santos, J.M.R.C.A., 2021. Circular bioeconomy strategies: From scientific research to commercially viable products. J. Clean. Prod. 295, 126–407. https://doi.org/10.1016/j.jclepro.2021.126407

Business Council for Sustainable Development (BCSD) Portugal, 2021. CEO's Guide to the Circular Bioeconomy. Available at https://bcsdportugal.org/bcsd-portugallanca-guia-do-ceo-para-a-bioeconomia-circular/.

Business Joensuu, 2021. Joensuu shows the way to forest bioeconomy [WWW Document]. URL https://www.businessjoensuu.fi/en/operational-environment/spearheads-of-expertise/forest-bioeconomy/ (accessed 5.17.21).

Canteri-Schemin, M.H., Fertonani, H.C.R., Waszczynskyj, N., Wosiacki, G., 2005. Extraction of pectin from apple pomace. Brazilian Arch. Biol. Technol. 48, 259–266. https://doi.org/10.1590/S1516-89132005000200013

Carus, M., Dammer, L., 2018. The "Circular Bioeconomy" Concepts, Opportunities and Limitations. Hürth. Available at www.bio-based.eu/nova-papers.

Carvalho, P., 2018. Dynamics of rural low density spaces in Portugal. J. Mediterr. Geogr. 130. https://doi.org/https://doi.org/10.4000/mediterranee.10516

D'Amato, D., Veijonaho, S., Toppinen, A., 2020. Towards sustainability? Forest-based circular bioeconomy business models in Finnish SMEs. For. Policy Econ. 110, 101848. https://doi.org/10.1016/j.forpol.2018.12.004

Dhillon, G.S., Brar, S.K., Verma, M., Tyagi, R.D., 2011. Enhanced solid-state citric acid bio-production using apple pomace waste through surface response methodology. J. Appl. Microbiol. 110, 1045–1055. https://doi.org/10.1111/j.1365-2672.2011.04962.x

Douro Intermunicipal Community, 2015. Integrated Strategy for Territorial Development of the Douro Region (2014-2020) [WWW Document]. URL https://www.norte2020.pt/sites/default/files/public/uploads/programa/EIDT-99-2014-01-020_Douro.pdf (accessed 5.13.21).

Environmental Performance Index, 2020. 2020 EPI Results [WWW Document]. URL https://epi.yale.edu/epi-results/2020/component/epi (accessed 12.25.21).

European Commission, 2019a. The European Green Deal. Communication from the commission to the european parliament, the european council, the council, the european economic and social committee and the committee of the regions. Available at https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11e.

European Commission, 2019b. EU Bioeconomy: creating sustainable resource-efficient bio-based products, including alternatives to plastic [WWW Document]. EU Sci. HUB. URL https://ec.europa.eu/jrc/en/science-update/eu-bioeconomy-creating-sustainable-resource-efficient-bio-based-products-including-alternatives (accessed 5.17.21).

FAOSTAT, 2019. World apple production [WWW Document]. Food Agric. Organ. United Nations. Stat. database. URL http://www.fao.org/faostat/en/#data/QC (accessed 3.29.21).

GPP, 2019. Office of Planning, Policy and General Administration. Analysis and Prospective Notebooks [WWW Document]. URL https://www.gpp.pt/index.php/ (accessed 5.17.21).

Hetemäki, L., Hanewinkel, M., Muys, B., Ollikainen, M., Palahí, M., Trasobares, A., 2017. Leading the way to a European circular bioeconomy strategy. From Science to Policy 5. European Forest Institute. Available at https://efi.int/sites/default/files/files/publication-bank/2018/efi_fstp_5_2017.pdf.

Institute for Nature Conservation and Forests, 2019. 6th National Forest Inventory, v1.0. Available at http://inforcna.pt/Media/Files/201979_Ifn6PrincipaisResultadosJun2019.pdf.

Intermunicipal Community, 2021. Territory [WWW Document]. Terras de Trás-os-Montes. URL https://www.cim-ttm.pt/pages/441 (accessed 5.13.21).

Luke, 2021. Natural Resources Institute Finland promotes bioeconomy and sustainable use of natural resources. [WWW Document]. Nat. Resour. Inst. Finl. URL https://www.luke.fi/en/ (accessed 5.17.21).

Mantell, S., Van Hove, P., 2008. Briefing: Agriculture and development. Proc. Inst. Civ. Eng. Eng. Sustain. 161, 157–159. https://doi.org/10.1680/ensu.2008.161.3.157

Masoodi, F.., Sharma, B., Chauhan, G.S., 2002. Use of apple pomace as a source of dietary fiber in. Plant Foods Hum. Nutr. 57, 121–128. https://doi.org/10.1023/A:1015264032164

Matiuti, M., Hutu, I., Diaconescu, D., Sonea, C., 2017. Rural pole for competitivity: A pilot project for circular bioeconomy. J. Environ. Prot. Ecol. 18, 802–808.

May, C.D., 1990. Industrial pectins: Sources, production and applications. Carbohydr. Polym. 12, 79–99. https://doi.org/https://doi.org/10.1016/0144-8617(90)90105-2

Moslemi, M., 2021. Reviewing the recent advances in application of pectin for technical and health promotion purposes: From laboratory to market. Carbohydr. Polym. 254, 117324. https://doi.org/10.1016/j.carbpol.2020.117324

Muizniece, I., Zihare, L., Pubule, J., Blumberga, D., 2019. Circular Economy and Bioeconomy Interaction Development as Future for Rural Regions. Case Study of Aizkraukle Region in Latvia. Environ. Clim. Technol. 23, 129–146. https://doi.org/10.2478/rtuect-2019-0084

National Official Journal, 2020. Major Planning Options for 2020, No. 64/2020 Series I of 2020-03-31. Portugal.

Neves, A., Godina, R., Azevedo, S.G., Pimentel, C., Matias, C.O., 2019. The Potential of Industrial Symbiosis : Case Analysis and Main Drivers and Barriers to Its Implementation. Sustain. 11, 1–68.

Nordic Co-operation, 2016. 10 facts about the Nordic Region and co-operation [WWW Document]. URL http://www.norden.org/en/fakta-om-norden-1/the-population (accessed 12.17.21).

Nordic Council of Ministers, 2017. Nordic Bioeconomy 25 cases for sustainable change. Copenhagen. Available at http://dx.doi.org/10.6027/ANP2016-782. https://doi.org/10.6027/ANP2016-782

Nordregio, 2011. Perspectives on rural development in the Nordic countries - Policies, governance, development initiatives, Nordregio Working Paper 2011:3.

Ong, V.Z., Wu, T.Y., 2020. An application of ultrasonication in lignocellulosic biomass valorisation into bio-energy and bio-based products. Renew. Sustain. Energy Rev. 132, 109924. https://doi.org/10.1016/j.rser.2020.109924

Paula, 2020. Forest Bioeconomy Cluster in North Karelia leads the way to a more sustainable region [WWW Document]. East North Finl. Ind. Transit. URL https://elmoenf.eu/2020/02/14/forest-bioeconomy-cluster-in-north-karelia-leads-the-way-to-a-more-sustainable-region/ (accessed 5.17.21).

Perussello, C.A., Zhang, Z., Marzocchella, A., Tiwari, B.K., 2017. Valorization of Apple Pomace by Extraction of Valuable Compounds. Compr. Rev. Food Sci. Food Saf. 16, 776–795. https://doi.org/10.1111/1541-4337.12290

Portuguese Republic, 2020. National Energy and Climate Plan 2030. Resolution of the Council of Ministers.

Portuguese Republic, 2017. Leading the Transition - Action Plan for Circular Economy in Portugal: 2017-2020, Resolution of the Council of Ministers No. 190-A/2017. Available at https://eco.nomia.pt/contents/ficheiros/paec-pt.pdf.

Portuguese Republic, 2015. National Forestry Strategy. Resolution of the Council of Ministers.

Refsgaard, K., Kull, M., Slätmo, E., Meijer, M.W., 2021. Bioeconomy – A driver for regional development in the Nordic countries. N. Biotechnol. 60, 130–137. https://doi.org/10.1016/j.nbt.2020.10.001

Robeco, 2021. Country Sustainability: Visibly harmed by Covid-19. Available at https://www.robeco.com/media/3/2/5/325dd63882d778324dd13ad2122d8ecb_202108-country-sustainability-ranking_tcm17-31263.pdf.

Rupasinghe, H.P.V., Wang, L., Pitts, N.L., Astatkie, T., 2009. Baking and sensory characteristics of muffins incorporated with apple skin powder. J. Food Qual. 32, 685–694. https://doi.org/10.1111/j.1745-4557.2009.00275.x

Smárason, B.Ö., 2016. Porvaldseyri sustainability model - Collection and compilation of data. Framework of LCA. Deliverable T2.3.1. Northern Cereals – New Markets for a Changing Environment. Available at https://cereal.interreg-npa.eu/subsites/CEREAL/Sustainability-Model_Report_NPA_Cereal_DT231.pdf.

Sustainable Development Report, 2021. Rankings: The overall performance of all 193 UN Member States [WWW Document]. URL https://dashboards.sdgindex.org/rankings (accessed 12.25.21).

The Good Country Index, 2021. Countries' balance-sheet towards humanity and the planet [WWW Document]. URL https://index.goodcountry.org (accessed

12.25.21).

The Northern Regional Agenda, 2019. The Agri-Food Sector Approach, Northern Regional Coordination and Development Commission. Available at https://www.ccdr-n.pt/pagina/seminario-economia-circular-e-o-setor-agroalimentar.

Wiebe, K.S., Harsdorff, M., Montt, G., Simas, M.S., Wood, R., 2019. Global Circular Economy Scenario in a Multiregional Input-Output Framework. Environ. Sci. Technol. 53, 6362–6373. https://doi.org/10.1021/acs.est.9b01208

Yates, M., Gomez, M.R., Martin-Luengo, M.A., Ibañez, V.Z., Martinez Serrano, A.M., 2017. Multivalorization of apple pomace towards materials and chemicals. Waste to wealth. J. Clean. Prod. 143, 847–853. https://doi.org/10.1016/j.jclepro.2016.12.036

Figure captions

Fig. 1 Flow diagram of the structure of the study and its methodology.

Fig. 2 Industrial commodities obtained from different recovery strategies of apple pomace and its potential applications (adapted from Perussello et al., 2017).

Fig. 3 Brief description of the biomass logistics process (adapted from Marques et al. 2018).

Tables and Figures

Table 1 Selected companies, role of interviewees, main business areas, their respective residues or by-products generated, and current CEB practices being carried out by each one.

Company	Product / service	Interviewee	Waste and / or by-products identified	CBE practices currently adopted
A	Dried fruits trade	Food Engineer	Almond shell, almond skin, roasted almond kernels	Heating, fertilizers
B	Sausage production	Chief Executive Officer	Animal fat, bones	Animal feed
C	Apples trade	Technical Director	Defective apple, not suitable for sale	Juice industry, cider production
D	Apples trade	Chief Executive Officer	Defective apple, not suitable for sale	Juice industry
E	Sausage production	Chief Executive Officer	Animal fat, bones	None (managed by external services)
F	Forestry	Chief Executive Officer	Branches and foliage	Composting
G	Mushroom production	Chief Executive Officer	Spent mushroom substate	Land fertilizers
H	Wine production	Chief Executive Officer	Grape pomce, stems and lees	Distillation of alcoholic beverages
I	Sausage production	Chief Executive Officer	Animal fat, bones	Animal feed
J	Dried fruits trade	Chief Executive Officer	Chestnut husks, chestnut wash water	Heating, fertilizers
K	Sausage production	Chief Executive Officer	Bones	None (managed by external services)
L	Wine production	Winemaker	Grape stems	None
M	Mushroom production	Chief Executive Officer	Spent mushroom substate	Land fertilizers
N	Forestry	Chief Executive Officer	Branches, twigs and leaves	None
O	Forestry	Chief Executive Officer	Plant remains, plant substrates	Composting

Table 2 Flows of biological wastes identified in the region under study, categorized by activity in the three main addressed industrial sectors.

Sector / activity	Flow waste
Agrifood	
Sausage production	Animal fat Bones
Apples trade	Defective apple, not suitable for sale
Dried fruits trade	Almond and chestnut shells Almond and chestnut skin Roasted almond, not suitable for sale Chestnut washing water
Mushroom production	Spent mushroom substrates
Wine production	Grape stalks Grape pomace Lees
Forestry	
Pruning and forests cleaning	Plant remains (branches, twigs, leaves)

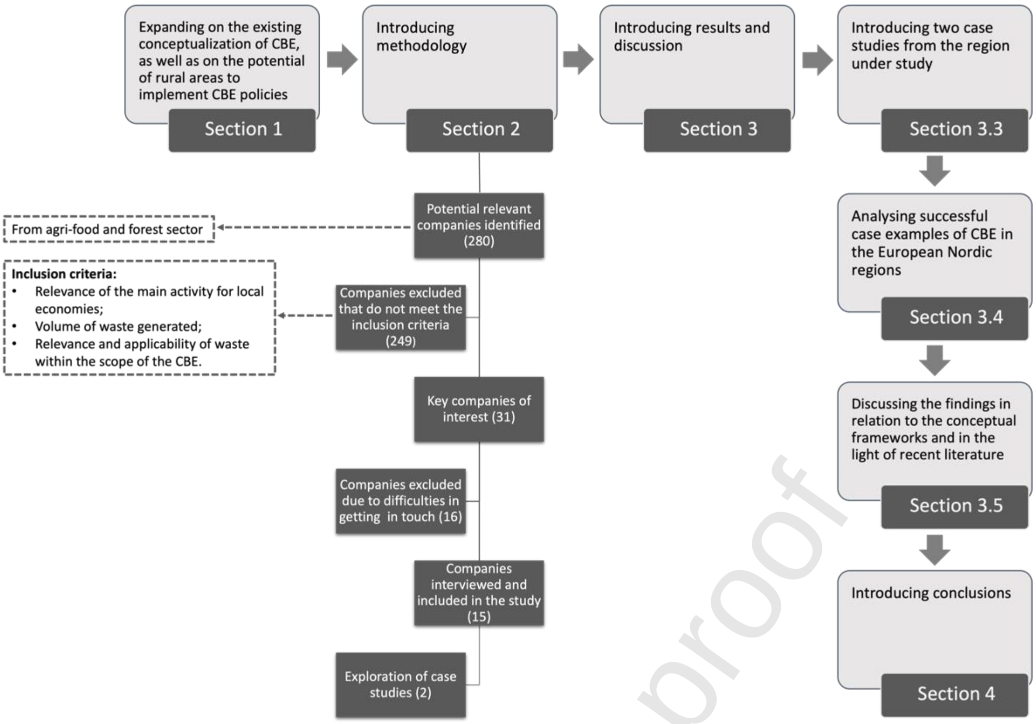

Expanding on the existing conceptualization of CBE, as well as on the potential of rural areas to implement CBE policies
Section 1
Introducing methodology
Section 2
Introducing results and discussion
Section 3
Introducing two case studies from the region under study
Section 3.3
From agri-food and forest sector
Potential relevant companies identified (280)
Inclusion criteria:
• Relevance of the main activity for local economies;
• Volume of waste generated;
• Relevance and applicability of waste within the scope of the CBE.
Companies excluded that do not meet the inclusion criteria (249)
Key companies of interest (31)
Companies excluded due to difficulties in getting in touch (16)
Companies interviewed and included in the study (15)
Exploration of case studies (2)
Analysing successful case examples of CBE in the European Nordic regions
Section 3.4
Discussing the findings in relation to the conceptual frameworks and in the light of recent literature
Section 3.5
Introducing conclusions
Section 4

Fig. 1

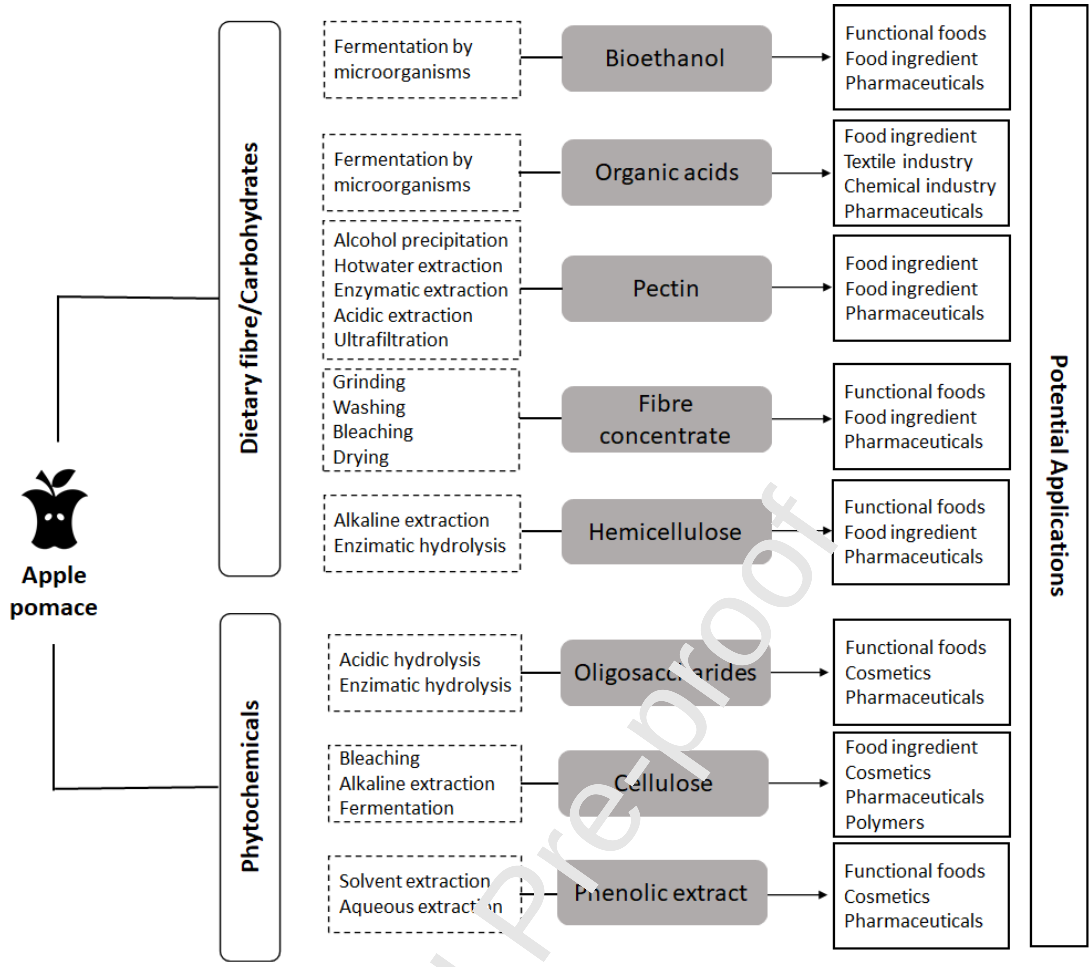

Apple pomace
Dietary fibre/Carbohydrates
Phytochemicals
Fermentation by microorganisms
Bioethanol
Functional foods
Food ingredient
Pharmaceuticals
Fermentation by microorganisms
Organic acids
Food ingredient
Textile industry
Chemical industry
Pharmaceuticals
Alcohol precipitation
Hotwater extraction
Enzymatic extraction
Acidic extraction
Ultrafiltration
Pectin
Food ingredient
Food ingredient
Pharmaceuticals
Grinding
Washing
Bleaching
Drying
Fibre concentrate
Functional foods
Food ingredient
Pharmaceuticals
Alkaline extraction
Enzimatic hydrolysis
Hemicellulose
Functional foods
Food ingredient
Pharmaceuticals
Acidic hydrolysis
Enzimatic hydrolysis
Oligosaccharides
Functional foods
Cosmetics
Pharmaceuticals
Bleaching
Alkaline extraction
Fermentation
Cellulose
Food ingredient
Cosmetics
Pharmaceuticals
Polymers
Solvent extraction
Aqueous extraction
Phenolic extract
Functional foods
Cosmetics
Pharmaceuticals
Potential Applications

Fig. 2

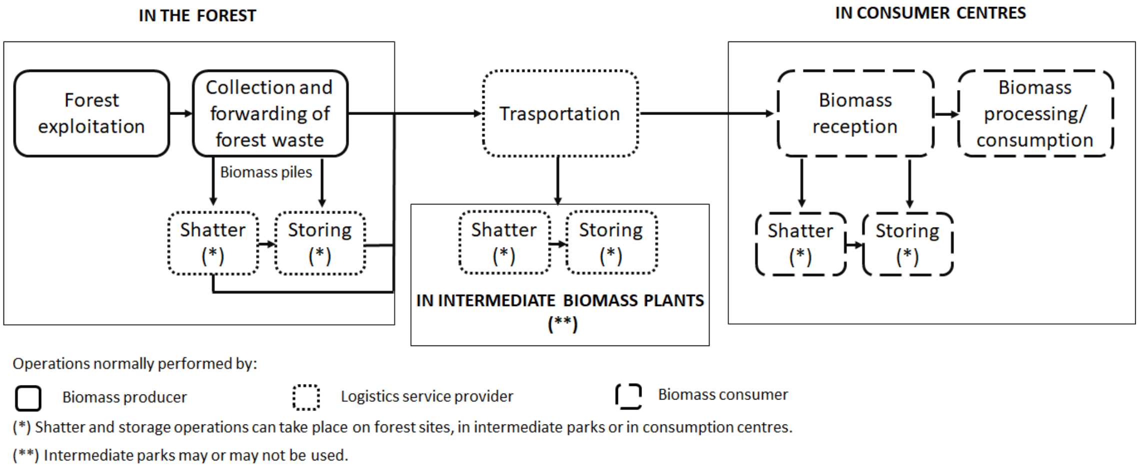

IN THE FOREST
IN CONSUMER CENTRES
Forest exploitation
Collection and forwarding of forest waste
Biomass piles
Shatter (*)
Storing (*)
Trasportation
Shatter (*)
Storing (*)
IN INTERMEDIATE BIOMASS PLANTS (**)
Biomass reception
Biomass processing/ consumption
Shatter (*)
Storing (*)
Operations normally performed by:
Biomass producer
Logistics service provider
Biomass consumer
(*) Shatter and storage operations can take place on forest sites, in intermediate parks or in consumption centres.
(**) Intermediate parks may or may not be used.

Fig. 3

CRediT authorship contribution statement

Ana Sofia Brandão: Conceptualization; Investigation; Methodology; Writing – original draft.

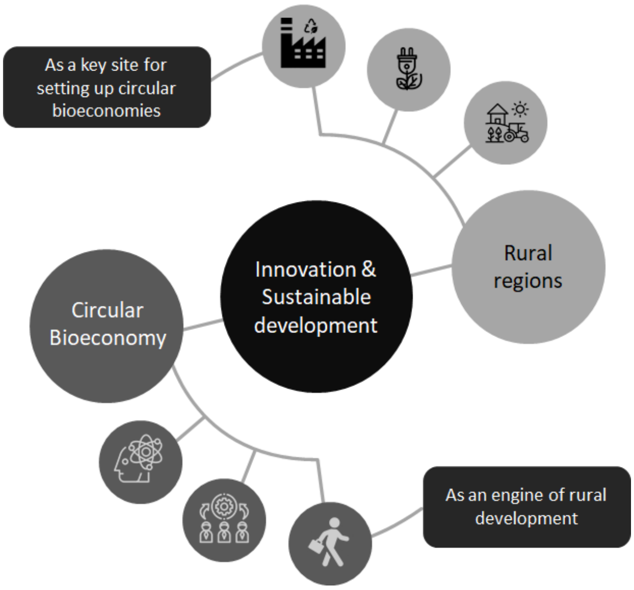
José M. R. C. A. Santos: Conceptualization; Funding acquisition; Project administration; Supervision; Writing – review & editing.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Graphical abstract



Highlights

- The potential of rural areas as a stage for the circular bioeconomy.
- A characterization of biological resources from the northern interior of Portugal.
- Comparison with the successful European Nordic (circular) bioeconomy model.
- Lack of synergies and low levels of applied education hinder the circular bioeconomy.
- Partnership's innovation and trust-based cultural profile are key to sustainable growth.