

LOCAL 2030
KNOWLEDGE AND SCIENTIFIC NETWORK

Sustainable Valorization of Arboricultural By- Products for Circular Economy Development

Policy Paper – 2026



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PREFACE

Achieving the 2030 Agenda requires more than translating global goals into national targets – it demands that sustainable development be rooted in the realities, needs, and capacities of local territories. Local and regional governments are indispensable actors in this process: they deliver essential services, address inequalities on the ground, and turn policy commitments into concrete actions. Yet this critical role is only fully effective when backed by strong evidence, meaningful knowledge exchange, and coherent governance across levels.

The Local2030 Knowledge and Scientific Network (KSN) was established within the UN Local2030 Coalition precisely to respond to this need. As a dynamic global platform, KSN connects young researchers, policymakers, community leaders, and practitioners around a shared mission: to harness science for sustainable development with local impact. It does so by aligning academic inquiry with the specific priorities of local development stakeholders, while amplifying research findings as inputs to SDG-related global processes.

Central to this approach is the understanding that research must not only be produced – it must be translated into policy and action. KSN promotes a more dynamic and responsive model of academia, one that co-creates scalable solutions rooted in scientific evidence and community priorities, and that empowers local actors with the skills, tools, and institutional support needed to engage in evidence-based decision-making and influence policy. Through its Country Pilots – sponsored by the Italian government and implemented by UN-Habitat and the Centro Studi di Politica Internazionale (CeSPI ETS) – and Innovation Labs, the network operationalizes this vision by connecting universities and students with local policymakers, enabling interdisciplinary collaboration and capacity-building in territories across Africa, Asia, and Latin America and the Caribbean.

Action-research is the methodological backbone of this work. Territories are engaged not as passive subjects of study, but as spaces for experimentation and learning, where sustained interaction between researchers, local governments, civil society, and communities drives learning, adaptation, and co-creation. By combining quantitative and qualitative methods – data analysis, spatial assessments, stakeholder engagement, and participatory approaches – this process generates a comprehensive and grounded understanding of local dynamics, inequalities, and development opportunities.

This policy paper is the result of that process. It reflects the outcome of collaboration between academic research, territorial analysis, and multi-stakeholder

dialogue, in the spirit of the KSN's core objective: translating research into policy and action. Its aim is to offer context-sensitive analysis and practical policy recommendations that can inform SDG localization at the local level – bridging the gap between global agendas and the communities that will ultimately determine their success.

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FOREWORD

Tunisia, like many Mediterranean countries, benefits from a rich and diverse arboricultural heritage, particularly in the cultivation of olives, almonds, pistachios, palms and other fruit trees. Tunisia ranks eighth in the world for almond production, seventh in the world for pistachio cultivation, and 4% of the world's palm tree plantation area (FAO, 2025).

While these sectors are vital to rural livelihoods and national exports, they also generate significant quantities of by-products prunings, leaves, peels, pulp and other organic residues which are often left unmanaged. In most cases, these by-products are discarded, burned or left to decompose, resulting in lost economic opportunities and environmental degradation.

In the context of growing environmental concerns, resource scarcity and the global transition towards sustainable development, the valorisation of tree crop by-products represents a promising but underexploited avenue. Converting these organic residues into useful products such as compost, bioenergy, natural fertilisers, bioplastics or inputs for agro-industries can add value, reduce waste and support a circular economy approach in Tunisia's agricultural sector.

In this context, municipalities play a crucial role in the integrated management of agricultural and agri-food waste. As local authorities, they are at the forefront of organising the collection, recovery and reuse of this waste. The municipality of Sousse, which has implemented several innovative waste management projects, has been an essential partner in this work. This close collaboration has enabled a better understanding of local needs, the testing of appropriate solutions and the proposal of concrete strategies for the recovery of agricultural by-products.

Recovering these residues to create compost, bioenergy, natural fertilisers, bioplastics or inputs for agro-industries represents a significant opportunity to strengthen the circular economy and the sustainability of the Tunisian agricultural sector. This guide builds on this perspective, proposing feasible strategies and public policy recommendations that transform by-products into valuable resources. Drawing on national realities and international best practices, it advocates an integrated framework that combines innovation, research, public-private partnerships and capacity building for sector stakeholders.

This policy paper is based on the importance of bridging the gap between waste generation and resource recovery. It aims to propose feasible strategies and policy recommendations that can turn these by-products from a burden into an opportunity.

Drawing on both national realities and international best practice, the paper advocates an integrated framework that includes innovation, research, public-private partnerships and capacity building for stakeholders along the value chain.

We hope that this document will inform decision-makers, practitioners and researchers, and inspire collaborative efforts to integrate circularity into Tunisian tree farming systems. Building a more sustainable and resilient agri-food sector is not only a national imperative, but also a shared responsibility.

November, 2025

Sousse, Tunisia.

1. INTRODUCTION

Tunisian arboriculture is a strategic sector, accounting for around 30% of total agricultural production and making a significant contribution to food security and the national economy. The sector is divided between rain-fed and irrigated crops, with a total area of nearly 450,000 hectares under cultivation. Irrigated crops account for 90% of fruit production. (GIZ. 2014; Burdeau, 2018; AgriTunisie, s.d.; Guides Ulysse, s.d.; Tunisia Tourism, s.d.).

Economically, arboriculture accounts for 12% of agricultural GDP, 9-10% of agricultural investment, and 10% of exports in the sector (GIZ. 2014). Annual production reaches approximately 1.2 million tonnes, 10% of which is exported. The sector is also a major source of employment, accounting for 16% of the permanent agricultural workforce and 50% of the seasonal workforce (GIZ. 2014), but also generates significant amounts of organic residues and by-products throughout their production and processing cycles which, despite their potential value, remain largely underutilised or unmanaged.

Currently, most of these by-products are treated as waste, often burned, dumped on fields or left to rot, resulting in avoidable environmental impacts such as greenhouse gas emissions, soil degradation and air pollution (Castagna et al., 2025; World Bank, 2024). This linear 'produce-use-dispose' approach contrasts sharply with the principles of a circular economy, where waste is minimised and every product has the potential to be reused as a resource (EcoFeed, 2025).

With increasing pressure to improve local sustainability, reduce agricultural waste and mitigate climate change, Tunisia is at a critical juncture (Salman, 2021). The sustainable recovery of agricultural by-products offers a unique opportunity to transform a long-standing environmental responsibility into a driver of innovation, green entrepreneurship and rural economic development (Castagna et al., 2025).

By adopting the principles of the circular economy (reuse, recycling and recovery), Tunisia can move towards more regenerative agricultural systems and create new markets for bio-based products, organic soil improvers, renewable energy and eco-materials (Subnational Finance, 2024).

This national transition is fully aligned with the 2030 Agenda for Sustainable Development (Fig. 1), which recognises the interconnected nature of food systems, natural resources, livelihoods and climate resilience. However, current practices such as open burning, landfilling and the informal dumping of agricultural by-products remain widespread. This reflects deeper structural challenges, including a

lack of targeted regulatory incentives, an absence of structured local value chains, limited data availability and a weak science-policy-practice interface.

The FAO emphasises that achieving the Sustainable Development Goals (SDGs) requires an integrated approach to agriculture, fisheries, forestry, and land and water management (FAO, 2017b). This policy framework primarily contributes to SDG 12.5 (substantially reducing waste generation through prevention, reduction, recycling, and reuse), SDG 13.2 (integrating climate change measures into national policies and planning), and SDG 11.6 (reducing the environmental impact of cities, including through improved municipal waste management). SDG2, which aims to 'end hunger, achieve food security and promote sustainable agriculture', is closely interconnected with other poverty-related goals (SDG1), as well as those relating to health (SDG3), gender equality (SDG5), water (SDG6), decent work (SDG8), innovation (SDG9), reduced inequalities (SDG10), responsible consumption and production (SDG12), climate action (SDG13), and the protection of ecosystems (SDGs 14 and 15).

The FAO's forward-looking analysis in *The Future of Food and Agriculture: Alternative Pathways to 2050*, highlights the indispensable nature of transforming food systems towards sustainability, resilience, and circularity in order to achieve these goals globally (FAO, 2018). In this context, municipalities play a pivotal role as the main local stakeholders responsible for waste management (Salman, 2021). Their involvement enables the organisation of the collection, sorting and recovery of agricultural by-products, thus facilitating the implementation of sustainable, region-specific solutions. The municipality of Sousse, for example, is involved in various innovative waste management initiatives and is playing a key role in developing recycling practices for arboricultural waste.

Subsequent sections of this policy paper will propose specific indicators and institutional arrangements to support implementation and monitoring, ensuring alignment with national SDG reporting frameworks and reinforcing a results-based management approach that links local actions to higher-level development outcomes.

2. KEY POLICY ISSUES

2.1. High Volume of Arboricultural waste and environmental impact

Arboricultural waste is a specific type of organic waste resulting primarily from the pruning, trimming, maintenance or felling of trees in agricultural, forest or urban areas (Toghiani et al., 2023). These residues typically comprise branches, leaves, twigs, bark, and unprocessed fruit and nut shells (Shaikhiev et al., 2021). While precise quantitative data on global arboticultural waste production is limited, its contribution to overall organic waste flows can be estimated based on general statistics on solid waste (Toghiani et al., 2023). According to a World Bank report (2018), global municipal waste production was approximately 2.01 billion tonnes per year in 2016, a figure which could reach 3.4 billion tonnes by 2050 if no sustainable management strategy is implemented (Louis, 2024). Organic waste accounts for a significant proportion of this total, and tree residues in particular remain a largely underutilised resource.

2.1.1 Different origins of Arboricultural waste

Arboticultural waste can be divided into different categories according to its origin.

Waste from agricultural operations

This arboticultural waste mainly comes from the maintenance and harvesting of plantations. First, there is the residue generated by pruning and trimming plantations. This includes waste from pruning olive trees (Anvari et al., 2024), trimming date palms (Batouche, 2021) and felling trees at the end of their production cycle, such as almond trees (Moussa, 2017). Secondly, other residues are produced during or after harvesting. These include date palm fronds and rachises after the dates have been picked (Batouche, 2021), olive pits and pomace from harvesting and processing (Anvari et al., 2024), leaves and stems after harvesting (Moussa, 2017; Fereidooni et al., 2024). Finally, forestry generates by-products such as branches, treetops and cutting residues that are not used for timber (Anvari et al., 2024). Although these agricultural and forestry wastes are often overlooked, they have great potential for recovery and can contribute to the implementation of more sustainable agricultural and forestry practices.

Agro-industrial arboticultural waste

This waste comes from processing agricultural products into food or non-food items. These residues are produced at various stages of the industrial process and vary depending on the relevant sector. For instance, orange peels are produced when citrus fruits are processed into juice or concentrates (Boumediene et al., 2015). Similarly, the production of olive oil generates two main types of by-product: olive pomace and spent olive pomace (Anvari et al., 2024).

In the case of the oil palm industry, palm kernel shells, produced during palm oil extraction, are also an important by-product (Koti, 2022). Although these agro-industrial by-products are often underestimated, they represent considerable environmental and economic recovery potential. Their integrated management is part of a circular economy approach aimed at limiting environmental impacts while promoting the development of sustainable industries.

Industrial and agri-food arboricultural waste

Waste from the agri-food industry and other sectors that handle tree-based raw materials constitutes a significant proportion of organic waste. These by-products, which are mainly generated during the processing of fruit and the woody parts of trees, have significant potential for recovery. For instance, almond shells (Anvari et al., 2024), almond and fig tree stems (Anvari et al., 2024), almond husks (Galanakis, 2021), pistachio industry waste includes shells, skins and outer husks, (Toghiani et al., 2023), are classified as agricultural residues. Furthermore, although residues from the processing of citrus fruits (Boumediene et al., 2015), apples, pears and date palms are less well documented than those from olives, they nonetheless represent valuable agro-industrial waste products (Ejemni et al., 2006). All these by-products are therefore valuable resources for developing innovative industries, particularly in the bioeconomy, renewable energy and bio-based materials sectors.

2.1.2. Impact of arboticultural waste on the environment

Arboticultural waste includes trunks, branches, leaves, roots and other residues from tree maintenance or harvesting. It can be recycled as an organic resource through processes such as composting, mulching or conversion into bioproducts (Margo, 2024). However, without proper management, these residues can have a significant environmental impact (Ducom et al., 2020). If left in the wild or improperly disposed of, their uncontrolled decomposition can lead to the release of potentially toxic compounds (Hamed et al., 2022). These substances result from the degradation of certain plant species and can infiltrate the soil and reach the water table, thereby compromising groundwater quality (Joël, 2022).

Furthermore, the excessive accumulation of untreated organic matter can promote the proliferation of pathogens, pests, and opportunistic microorganisms, thereby disrupting the ecological balance of local ecosystems (Toghiani et al., 2023). Improper management of this waste can also hinder the natural regeneration of soils and forests (Toghiani et al., 2023). Arboricultural waste plays a fundamental ecological role, particularly in the cycle of organic matter, soil structuring and maintaining microbial biodiversity. Therefore, its uncontrolled disposal can deplete soils of nutrients, reducing their fertility and undermining the resilience of ecosystems (Benito et al., 2006).

2.1.3. Estimation of by-products regenerated by arboriculture, an underutilized resource: case study of pistachio, almond, and palm crops

Scientific research shows that almost all agricultural by-products, considered waste, contain molecules and compounds that are of considerable value to the agri-food, cosmetics, pharmaceutical, and industrial sectors.

Almond residues, such as shells, skins, gums and cake, contain high levels of polyphenols, including condensed and hydrolysable tannins, flavonoids, phenolic acids and stilbenes such as polydatin (Barral-Martinez et al., 2021). They also contain compounds with strong antioxidant properties, including chlorogenic acid, isorhamnetin, catechin, protocatechuic acid and eriodictyol. They also contain polysaccharides with antioxidant and antiproliferative properties; triterpenoid acids such as betulinic, ursolic and oleanolic acids (Barral-Martinez et al., 2021); lipids rich in unsaturated fatty acids; bioactive proteins that modulate inflammation; volatile terpenes; and various simple sugars such as sucrose, fructose, glucose and xylose (Fig.6).

Pistachio tree by-products also have considerable potential (Fig.7): shells, accounting for around 70% of industrial residues, are primarily composed of cellulose and lignin, and contain polyphenols including monomeric flavonoids and gallic acid derivatives, as well as polysaccharides such as arabinogalactan, which is recognised for its immunostimulatory properties (Maccarronello et al., 2024; Cardullo et al., 2021; Capaldi et al., 2024; Zhang et al., 2020).

The residues of the palm tree, particularly the fibres, petioles, fluff and pits, are mainly composed of cellulose, hemicellulose and lignin. They also contain polyphenols, flavonoids and other bioactive secondary metabolites. Dates and their by-products contain phenolic compounds, antioxidants, fatty acids, simple sugars and minerals (Khardi et al., 2024).

This makes the palm tree a valuable source of biomaterials, bioenergy and prebiotics, such as xylo-oligosaccharides (XOS), as well as for various food and pharmaceutical applications (Fig.8).

This scientific importance was highlighted thanks to a collaboration between the municipality of Sousse and the Higher Institute of Agronomy of Chott Mariem as part of the KSN program, which made it possible to determine the following (Fig.9):

The number of palm trees planted in the municipality of Sousse

The different types of by-product generated by palm cultivation and by agro-industrial activities involving the processing of pistachios and almonds

2.2. Tunisian Arboriculture: A Double-Edged Pillar

2.2.1. Arboriculture production

Tunisia ranks eighth in the world for almond production (Fig.2), with 199 455 hectares planted with almond trees, representing approximately 13,500,000 trees producing around 70,000 tons (FAO, 2025). As for pistachio cultivation, Tunisia ranks seventh globally, with 26,855 hectares planted (Fig.3), a planting density of around 100 trees/ha in rainfed areas and 200 to 300 trees in irrigated areas, and an estimated production of 3,190 tons (FAO, 2025). As for palm tree cultivation, Tunisia hosts 5.5 million date palm trees spread over 40,976 hectares.

Tunisia's arboricultural sector generates substantial quantities of organic by-products annually, including pruning residues, leaves, stones, shells, and fruit pulp. Date palm cultivation includes 5.5 million trees (Fig.4) across 40,976 hectares, representing a major component of Tunisia's arboricultural production (FAO, 2025).

Despite this substantial biomass, the majority of these by-products are burned, landfilled, or left to decompose in open fields, resulting in environmental degradation and missed opportunities for resource recovery.

In the central Tunisian region, a major agricultural hub in Tunisia, the municipality generates approximately 266 tonnes of solid waste daily, with an average per capita waste generation of 0.47 kg (Mouhamed Ikbel, 2023).

While comprehensive data on agricultural waste in Sousse as well as almost of Tunisian municipalities, remains limited (Fig.5), the prevalence of almond and

pistachio cultivation in the area suggests that a significant portion of this waste is agricultural in nature.

The absence of structured waste management systems for organic residues results in:

- Increased greenhouse gas emissions, especially methane and CO₂, from decomposition and open burning;
- Contamination of soil and water through uncontrolled leaching of decomposing matter;
- Air pollution, especially in rural areas during the post-harvest and pruning seasons;
- Missed economic opportunities to process these by-products into high-value products.

These environmental and economic consequences highlight the urgent need for integrated strategies for the sustainable management of agricultural biomass (Middle East Institute, 2022).

Group 40, Grouped objectThe percentage quantification of each by-product generated by palm cultivation and by agro-industrial activities involving the processing of pistachios and almonds.

The physicochemical characteristics of palm tree by-products (leaves), pistachio tree by-products and almond tree by-products (shells).

The composition of a few chemical elements in palm tree by-products (leaves), pistachio tree by-products and almond tree by-products (shells).

Consequently, the by-products of pistachio, almond, and palm trees are emerging as highly valuable and versatile plant matrices with significant economic, industrial, and environmental potential.

2.3. Regulatory and Institutional Barriers

Existing waste management policies in Tunisia do not yet fully support the valorization of agricultural and arboricultural residues.

Although national strategies such as the National Solid Waste Management Program (ANGED, 2023) prioritize waste reduction and recycling, they remain

primarily focused on municipal and household waste, with limited attention to agricultural biomass recovery. The principal legal framework—Law No. 96-41 of June 10, 1996, on waste management and its control does not provide specific provisions to regulate, classify, or incentivize the reuse of agricultural by-products as inputs for bio-based industries (Middle East Institute, 2022; ANME, 2024).

The private sector also faces multiple structural barriers. Currently, there are no dedicated financial incentives, tax reductions, or subsidies encouraging investment in biological substrate production or agricultural residue transformation (AllAfrica, 2025). Public-private partnerships in the waste management sector remain scarce, and innovation in circular bioeconomy models is constrained by bureaucratic procedures, weak inter-ministerial coordination, and the absence of certification standards for composts and organic substrates derived from agricultural residues (BCDesk, 2024). Moreover, access to green credit and startup financing for enterprises developing sustainable technologies remains very limited, discouraging broader private participation (MEI, 2022).

From a territorial and urban planning perspective, instruments such as the Local Sustainable Development Plans (PLDD) and Municipal Investment Programs (PIM) seldom integrate agricultural waste valorization within their spatial and economic development frameworks.

Local authorities typically lack the technical expertise and financial capacity to establish dedicated infrastructure for organic waste collection, sorting, and transformation (African Clean Cities Platform, 2023). Furthermore, coordination between municipal, agricultural, and environmental actors remains weak, leading to fragmented and isolated initiatives rather than coherent circular economy strategies (Subnational Finance, 2023).

Like most Tunisian municipalities, the city of Sousse does not yet apply a differentiated valorisation strategy for agricultural biomass at the municipal scale.

In practice, residues from pruning, market activities, arboriculture or food processing are collected alongside general municipal waste and directed towards basic treatment processes such as methanisation, composting or, in many cases, direct landfill or soil burial (ANGED, 2023; ANME, 2024). Even when valorisation occurs, it is generally limited to low-value processes primarily aimed at reducing waste volume rather than producing high-quality bio-based products such as standardised compost, biochar or certified organic substrates (Fassatoui et al., 2024).

This situation is consistent with broader municipal trends observed nationwide (MDPI, 2024). In Sousse, municipal solid waste interventions under initiatives such

as the Waste Wise Cities programme continue to focus on improving cleanliness and basic waste management rather than developing dedicated agricultural biomass valorisation chains (African Clean Cities Platform, 2023). Overall, this municipal approach reflects the national context, which is characterised by limited technical capacity, insufficient regulatory guidelines specific to agricultural residues and an absence of integrated local strategies to foster the development of a circular bioeconomy (Ecomena, 2023; WasteCulture, 2022; Subnational Finance, 2023).

Therefore, strengthening the institutional framework requires revising national waste management policies to explicitly recognise agricultural residues as a strategic resource.

This involves developing clear technical guidelines and regulatory incentives for biomass utilisation, integrating circular economy principles into local planning tools and establishing national standards. Supporting pilot projects through green financing mechanisms, fiscal incentives and public–private partnerships could encourage sustainable agricultural waste valorisation and regional bioeconomy development (AllAfrica, 2025; ANME, 2024).

Despite the growing number of scientific studies highlighting the chemical, agronomic and economic value of agricultural by-products, there is still a Group 46, Grouped objectsignificant gap between academic findings and their implementation by local authorities, institutions and private organisations in Tunisia.

Numerous studies have demonstrated the potential of using pruning residues, agro-industrial by-products and livestock manure to produce high-quality compost, organic substrates, bioenergy or bio-based materials (Fassatoui et al., 2024; Ben Rejeb et al., 2021). Yet this knowledge is rarely translated into municipal strategies or private investment decisions.

This can be partly explained by the absence of robust institutional mechanisms for transferring knowledge to local decision-makers and practitioners, a lack of coordination between research institutions, municipalities and the private sector, and a lack of technical, regulatory or financial incentives to encourage the adoption of innovations based on research (African Development Bank, 2022; ANME, 2024). National reports also emphasise that agricultural waste streams remain poorly integrated into territorial planning and national circular economy strategies, despite their significant potential (UNEP, 2023; Subnational Finance Initiative, 2023).

Consequently, scientific findings often remain confined to academic publications, while practical waste management continues to prioritise disposal, primarily through landfilling, rather than recovery or value creation (ANGED, 2023). This

persistent science–policy–practice gap constitutes a major barrier to establishing circular value chains around agricultural biomass and limits the capacity of local and regional actors to adopt sustainable, bio-based development models.

3. PROPOSED SOLUTIONS

3.1. Opportunities for circular economy development

Globally, agricultural activities generate approximately 1.3 billion tonnes of food waste annually, accounting for nearly one-third of all food produced for human consumption (FAO, n.d.). This waste significantly contributes to environmental degradation, including greenhouse gas emissions and soil contamination.

In Tunisia, the situation mirrors this global trend. The country produces around 6.5 million tonnes of solid waste annually, with approximately 68% being organic (Chaher et al., 2020a; Chaher et al., 2020b; Abdulrahman, 2024).

According to EcoMENA (2024), Tunisia generates over 2.5 million tonnes of solid waste per year, a significant proportion of which comes from agricultural activities.

The transition from a linear waste model to a circular economy presents a strategic opportunity for Tunisia's arboriculture sector. By-products from olives, dates, citrus, almonds, and all other tree species can be reused in a wide range of sustainable products.

These circular economy practices can improve resource efficiency, reduce Tunisia's agricultural carbon footprint, and create new income streams for farmers, cooperatives and green entrepreneurs.

Agricultural waste can be conceptualised as a box of old LEGO bricks: rather than discarding it, its components can be disassembled and reused. Polyphenols (e.g. chlorogenic acid) represent the small, valuable pieces that confer specific functional properties, such as antioxidant and antimicrobial activity. Polysaccharides (gums) and lipids function as intermediate components, contributing to the texture and structural properties of derived products.

Cellulose, hemicellulose and lignin- collectively referred to as lignocellulosic components are the standard building blocks. They make up most of the box and can be transformed into new materials, such as culture substrates and biofuels, through decomposition or chemical modification. The objective of recovery is to salvage all these 'parts' in order to create new, high-value products instead of simply burning or throwing the box away (Fig.10).

These valuable molecules and components can be extracted from agricultural by-products, often referred to as waste, before they are sent for final recovery. This recovery process may involve using the by-products as:

- **Industrial valorisation: Eco-industry, composite and textile materials**

Due to their high cellulose and lignin content, certain arboricultural waste products such as walnut and almond shells, or woody stems, can be used as reinforcements in the production of composites and nanocomposites, or as a raw material for the production of durable textile fibres, replacing synthetic fibres (Moussa, 2017). In addition, lignocellulosic waste can also be processed into bioplastics, packaging materials and even building components (Fig.11).

- **Pharmaceutical, medical, and food valorization**

Several arboricultural by-products have interesting bioactive properties (Fig.12). For example, almond skins, walnuts and hazelnuts contain antioxidant compounds that can be used in food supplements or to develop functional pharmaceutical ingredients (Gaglio et al., 2023).

- **Environmental valorisation: adsorption and water treatment**

Certain residues, such as almond skins and shells, have possess adsorbent properties that can be used for wastewater treatment, due to their ability to bind heavy metals and organic pollutants (Fig.11; Fig.12). Their application in the field of pollution control contributes to more integrated and effective waste management (Shaikhiev et al., 2021).

The final valorisation stage, after all important molecules, substances and components have been extracted, involves using what is now considered waste in the following ways:

- **Agronomic valorisation**

Organic growth substrates: Olive pruning waste, almond and pistachio shells, and date palm fibre can be converted into compost, biochar, or peat alternatives, reducing dependence on imported substrates and synthetic fertilisers (Fig.13). Despite the abundance of locally available biomass, Tunisia currently imports significant amounts of peat for horticulture (ACEN Foundation, 2023).

Bio-based fertilisers and soil improvers: Pulp, almond and pistachio by-products, and organic residues from olive oil production can be processed into nutrient-rich materials that improve soil structure and microbial health (Fig.13).

Composting: Decomposed arboricultural waste can be used to produce nutrient- rich organic amendments (Fig.13) that enhance soil structure, water-holding capacity and fertility (Margo, 2024). Furthermore, residues such as olive pomace and cake can be converted into biofertilisers like Marbiocompost, thereby reducing the reliance on chemical inputs (Anvari et al., 2024).

• Energy Valorisation

Biogas and biochar: Through anaerobic fermentation, these wastes can be converted into biogas (Fig.14), a renewable energy source that is well-suited to rural areas and agricultural operations (Toghiani et al., 2023). The pyrolysis of lignocellulosic biomass produces biochar, a stable material that improves soil physicochemical properties, sequesters carbon and limits greenhouse gas emissions (Fereidooni et al., 2024).

Renewable energy: Biomass, such as olive pits and almond shells, has a high calorific value and can be used for producing briquettes or for anaerobic digestion to generate biogas, particularly in off-grid rural areas. (Fig.14).

• Urban planning valorisation

Palm kernel shells can be used to build low-traffic roads (University of Limoges and University of Abomey-Calavi, Benin). Additionally, the date industry produce waste during post-harvest sorting and grading operations (Ejemni et al., 2006). Furthermore, the processing of nuts such as pistachios, almonds, walnuts, hazelnuts and chestnuts produces shells and skins during the shelling and cleaning stages (Fereidooni et al., 2024). Similarly, fruits such as peaches, apricots, cherries and plums generate shells and skins during processing. All of these pits and shells could be used as an alternative to gravel in car parks, pathways, walkways in parks and playgrounds (Fig.15).

3.2. Let's solve the problem together

The role of each partner is defined in accordance with the key stages of the circular economy value chain (Fig. 16), distinguishing between those operating within the project's sphere of control and those within its broader sphere of influence. Engaging stakeholders is fundamental to the success of the project 'Sustainable Valorisation of Arboricultural By-Products for Circular Economy Development', since transforming arboricultural residues into secondary resources requires coordinated, multi-level action involving local, national and international stakeholders. Within the sphere of control, farmers and agricultural cooperatives act as primary biomass

providers, ensuring the availability of resources and the sustainable management of feedstock an essential prerequisite for any valorisation process. The expected outcome for this group is the establishment of reliable, organised supply chains for arboricultural residues, which will improve both resource efficiency and farmers' income diversification.

Within the sphere of influence, public authorities, municipalities, research institutions and private sector actors contribute to enabling conditions such as regulatory frameworks, technical innovation and market development. Their engagement is expected to lead to improved policy support, the development of structured local value chains, and the scaling up of sustainable practices.

Overall, this coordinated stakeholder approach aims to strengthen the circular economy ecosystem by linking resource mobilisation, technological innovation, and governance mechanisms across different levels of intervention.

• Ensuring resource availability and sustainable feedstock management 'Valorisation requires the effective availability of the resource'

Farmers and agricultural cooperatives, as the primary biomass providers, represent a critical entry point within the circular value chain. Their engagement supports the adoption of sustainable biomass management practices, including source separation, reduced open-field burning, and participation in pilot demonstration projects focused on the production of compost, biochar, and bio-based growing media. These actions are fully aligned with the EU Circular Economy Action Plan and SDG 12 (Responsible Consumption and Production). Local authorities, notably the Municipality of Sousse, act as territorial coordinators and facilitators by enabling the deployment of collection and pre-treatment infrastructure, providing operational support, and integrating biomass valorisation into local sustainable development strategies, urban planning instruments, and climate action plans. They also contribute to horizontal and vertical policy coherence by connecting research institutions, agricultural stakeholders, and market participants.

• Strengthening the science-policy-practice interface 'Valorisation requires in-depth knowledge of the resource'

Research and innovation institutions, including ISA-CM, the University of Sousse, CTAB and other public and private R&I organisations, contribute to evidence-based decision-making by characterising biomass streams, identifying bioactive compounds and functional properties, and developing scalable circular solutions and demonstrators. They reinforce the science-policy-society interface in line with Horizon Europe, EU mission-oriented R&I, and UN knowledge co-production

frameworks, while supporting capacity building and technology transfer to end users.

- **Enabling policy coherence, regulatory alignment, and investment readiness**
'Valorisation requires an enabling regulatory and institutional framework'

National public authorities, including the Ministries of Agriculture and the Environment, ANME and ANGED, play a key role in ensuring regulatory coherence, policy alignment and institutional coordination across sectors. Their involvement supports the creation of an enabling environment through data sharing, regulatory streamlining, and incentive mechanisms that de-risk investments and catalyse green and circular finance, in line with EU Green Deal objectives and SDG 13 (Climate Action).

- **Market uptake, innovation, and socio-economic impact**
'Valorisation goes beyond waste transformation'

SMEs, start-ups and industrial actors are recognised as key drivers of market uptake and innovation diffusion. Their investments in the upscaling and commercialisation of bio-based products contribute to the development of circular business models, local value chains, and decent job creation, supporting SDG 8 (Decent Work and Economic Growth) and territorial economic resilience.

Civil society organisations, NGOs and youth networks contribute to behavioural change, public awareness and community engagement, ensuring social ownership and inclusiveness. International partners, including UN-Habitat, FAO, UNEP, CeSPI, SwitchMed and the Local2030 Coalition, provide strategic support in the form of policy guidance, technical assistance, blended finance mechanisms and peer-learning platforms. This facilitates South-South and triangular cooperation and alignment with the 2030 Agenda for Sustainable Development.

This integrated, multi-stakeholder and multi-level governance approach supports the establishment of a territorial circular economy governance model, enhancing policy coherence, implementation effectiveness and long-term sustainability. The project contributes to the localisation of the SDGs and demonstrates a replicable and scalable model for the sustainable utilisation of arboricultural by-products in Mediterranean and EU Neighbourhood contexts.

4. POLICY RECOMMENDATIONS OR FUTURE STRATEGIES AND ACTIONABLE POINTS

In the face of mounting challenges related to agricultural waste management, the depletion of natural resources, and the imperative to hasten the shift towards a circular economy, the sustainable utilisation of tree crop by-products has become a strategic imperative for Tunisia.

The following public policy recommendations aim to strengthen the coherence and effectiveness of public action by promoting the integration of innovative, locally adapted and economically viable solutions within existing regulatory, institutional and financial frameworks. The recommendations seek to guide public decision-making towards structuring sustainable value chains, mobilising public and private investments, and creating synergies between national and local actors. This is in line with the country's commitments to sustainable development, ecological transition, and climate change mitigation.

- **Establish an Incentive Policy and Investment Framework**

Public authorities should introduce targeted tax incentives, subsidies and dedicated financing mechanisms to encourage private-sector investment in the valorisation of agricultural waste and the production of bio-based substrates. In particular, incentives and tax benefits should be provided to micro, small and medium-sized enterprises (MSMEs) that convert waste into valuable products, such as livestock feed derived from insect farming using upcycled food waste. Public-private partnerships are crucial for scaling up pilot projects into operational, large-scale solutions.

At the same time, Law No. 41 of 1996 on Waste and Its Management must be fully and effectively implemented to support these initiatives. This law constitutes the main legal framework for waste management, including classification, collection, treatment, and monitoring, with subsequent amendments.

- **Integrate Agricultural By-product Valorization into National Strategies**

To ensure regulatory coherence and sustainable institutional support, valorisation value chains should be systematically incorporated into national policies on agriculture, waste management, climate and the circular economy. It is recommended that a central ministry be designated to plan and implement schemes that facilitate the efficient utilisation of agricultural and food waste using appropriate technologies and machinery within a cluster approach.

- **Strengthen Applied Research and Knowledge Transfer**

Governments and donors are encouraged to increase funding for applied research and innovation in composting, biochar and bio-based substrates.

It is also recommended that knowledge transfer mechanisms linking research institutions, farmers, cooperatives and public decision-makers are institutionalised.

- **Develop Clear Quality and Safety Standards**

Developing national quality and safety standards for organic substrates derived from agricultural by-products is essential to build market confidence, facilitate commercialisation, and ensure environmental and health protection. These standards should be developed collaboratively by key institutions, such as the national standards body, relevant ministries (e.g. agriculture and the environment) and research institutes, while their enforcement should be overseen by the relevant regulatory bodies. In this context, the pilot projects implemented in Sousse can play a strategic role by generating empirical data, testing prototypes and providing evidence-based contributions to the design, validation and continuous improvement of these standards.

- **Integrate Valorization Actions into Territorial and Municipal Planning**

Local authorities are encouraged to integrate the valorisation of agricultural by-products into local sustainable development plans, municipal circular economy strategies and local climate action plans. This will strengthen urban-rural linkages, reduce organic waste flows and promote the creation of green jobs.

- **Institutionalize Stakeholder Engagement and Capacity Building**

Policy frameworks should ensure the active involvement of agricultural organisations, cooperatives, municipalities, civil society and the private sector in co-designing and implementing projects. These multi-actor partnerships should deliver tangible outputs, such as funded pilot projects, technical guidelines and peer-

learning exchanges, while targeted awareness-raising and capacity-building initiatives should support the local uptake of bio-based substrates. Such efforts can lead to concrete outcomes, including improved access to blended finance and the adoption of international best practice, particularly in pilot regions such as Sousse.

- **Mobilize Strategic International and Regional Partnerships**

National and local stakeholders are encouraged to form partnerships with United Nations agencies (UN-Habitat, UNDP, UNEP and FAO), the Local2030 Coalition and European and Mediterranean cooperation frameworks, in order to secure funding, technical assistance and the exchange of best practices. This will position pilot territories such as Sousse as scalable models.

5. CONCLUSION

The sustainable utilisation of arboricultural by-products offers Tunisia a strategic opportunity to transition from a linear waste management model to a circular economy within the agricultural sector. The analyses presented in this report highlight that, while agricultural waste management is rooted in local contexts, it carries broader implications for national economic development, environmental sustainability, and policy frameworks. In this transition, municipalities such as Sousse play a pivotal role; however, their ability to effectively manage and valorise these resources remains constrained by limited access to appropriate materials, technologies, and skilled human resources.

5.1. Objective and Expected Outcomes

5.1.1. Overall objective:

To establish an integrated and circular system for the valorisation of arboricultural by-products, contributing to sustainable agriculture and local economic development in Tunisia.

Key outcomes:

Short term: Improved local waste management practices and initiation of pilot projects for substrate production.

Medium term: Development of sustainable value chains, job creation, and increased access to innovative financing mechanisms.

Long term: Enhanced environmental sustainability, reduced dependency on imported substrates, and strengthened institutional frameworks supporting circular economy practices.

Scientific evidence confirms that residues from almond, pistachio and palm cultivation are rich in bioactive compounds, lignocellulosic materials and nutrients that can be converted into high-value products, including bio-based substrates, organic fertilisers, bioenergy and materials for industrial and environmental applications. However, there is a significant gap between research findings and practical implementation, largely due to fragmented regulatory frameworks, insufficient financial incentives, and limited coordination between public authorities, private enterprises, and research institutions.

Addressing these challenges requires a multi-level, multi-stakeholder approach. Tunisia can create robust value chains that transform agricultural residues into sustainable resources by integrating applied research, capacity building, public-private partnerships, and strategic international cooperation. Incorporating circular economy principles into national and municipal policies, developing quality standards, and mobilising innovative financing mechanisms are all crucial steps towards achieving this goal.

Ultimately, the sustainable management and utilisation of arboricultural by-products will mitigate environmental risks, enhance resource efficiency, and create new economic opportunities.

FIGURES

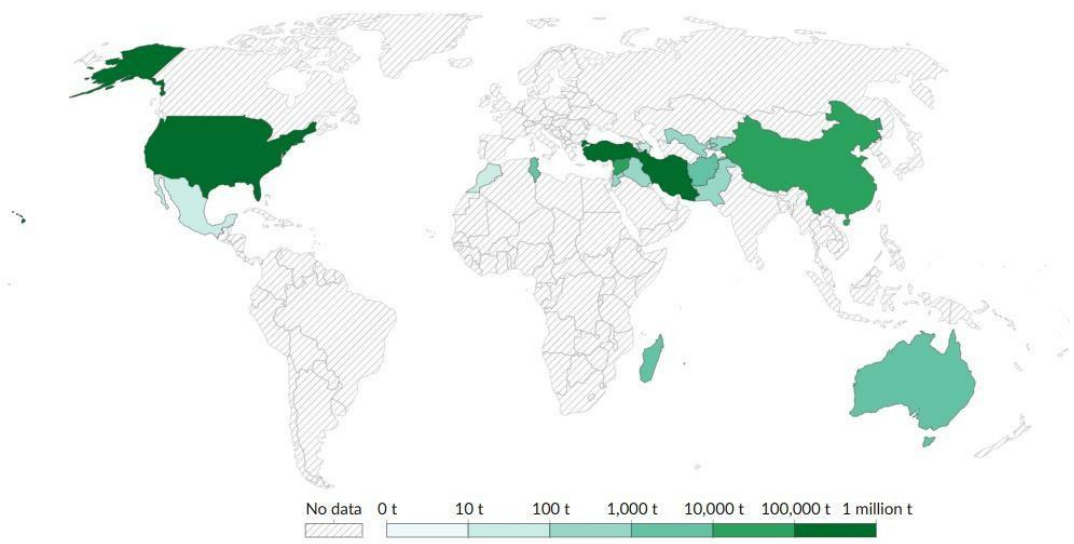


Figure 1: Sustainable Development Goal and agriculture

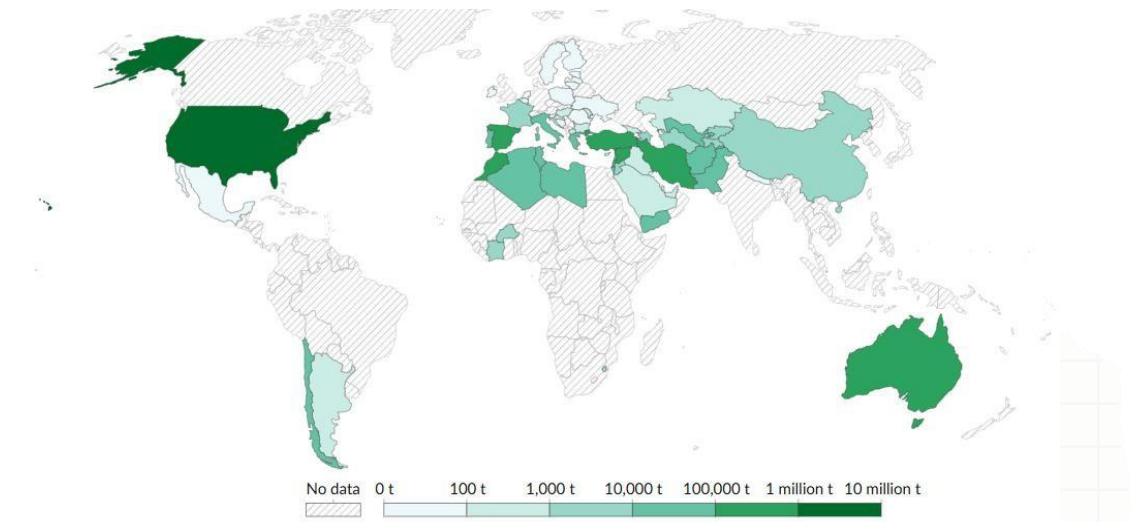


Figure 2: Productions of almonds , 2023

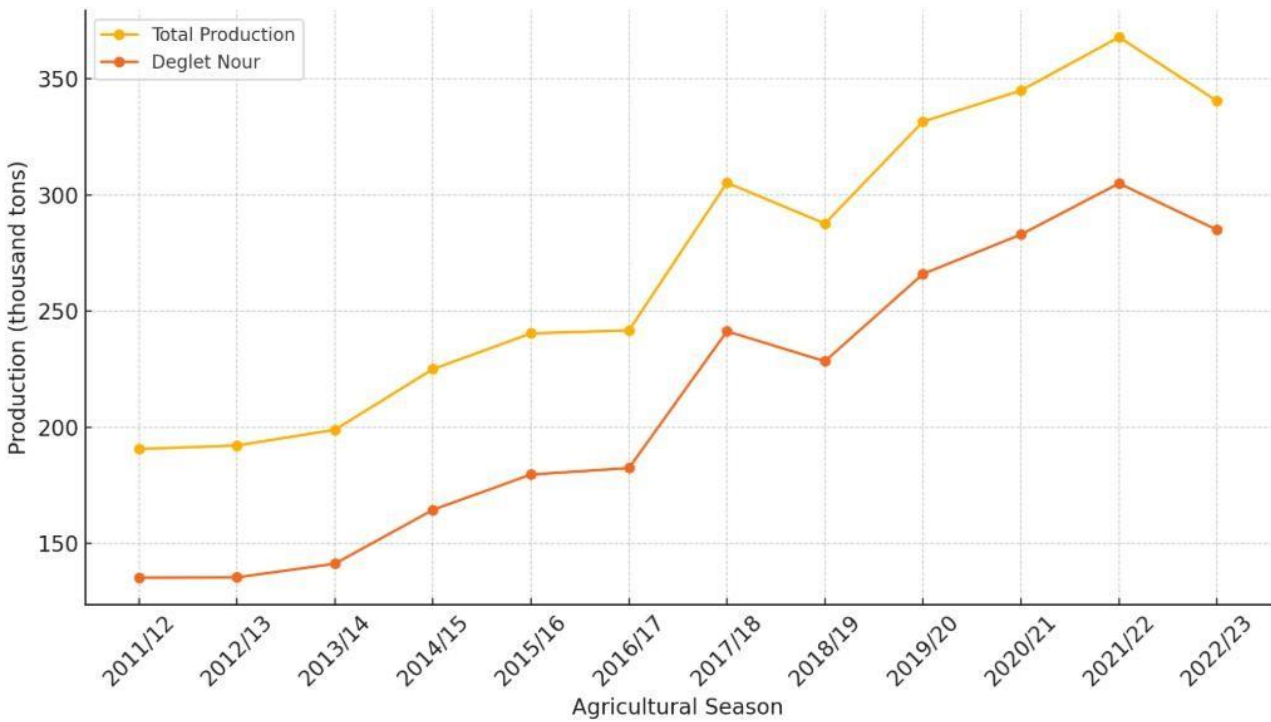


Figure 4: Evolution of Date production in Tunisia from 2011 to 2023

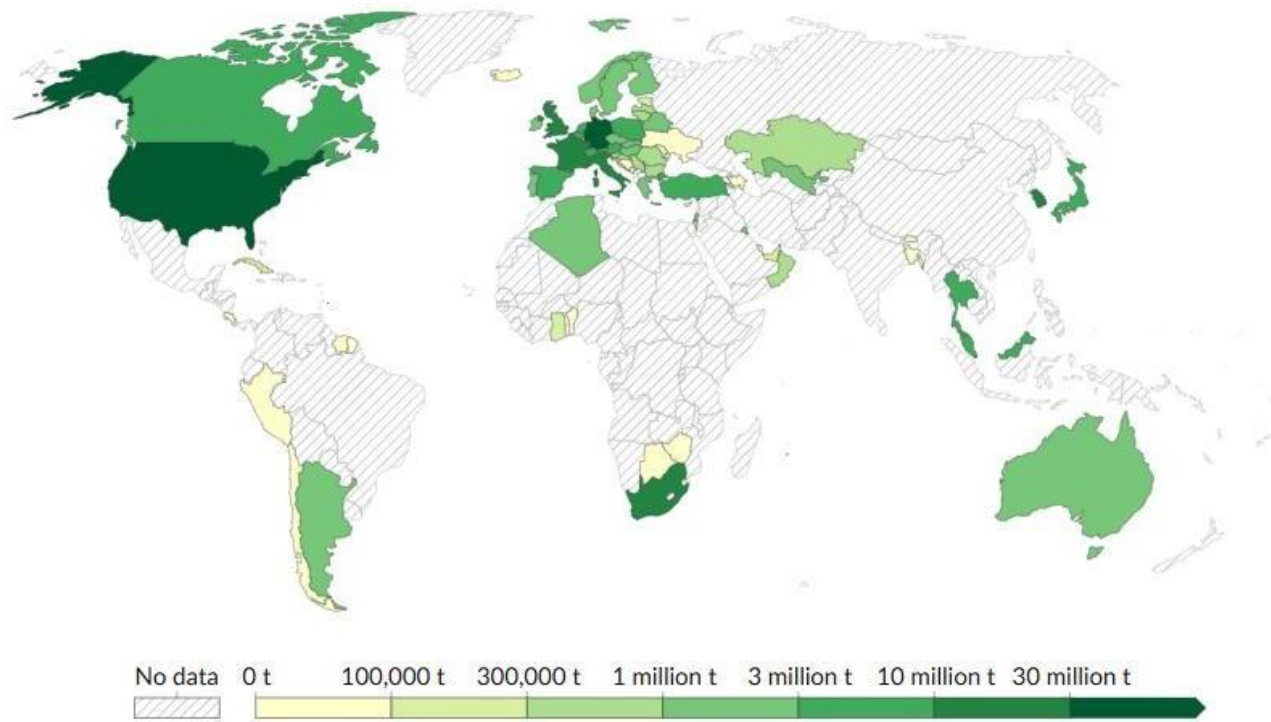


Figure 5: Rate of recycled municipal waste , 2022

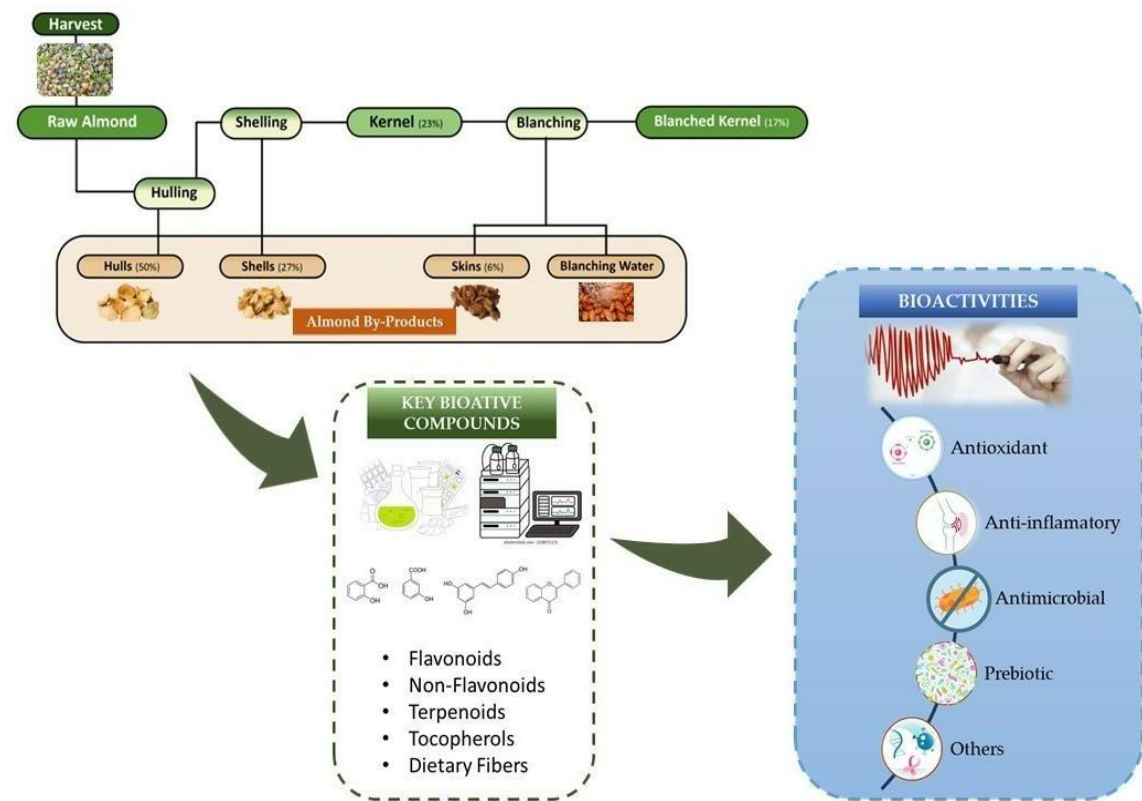


Figure 6. Almond By-Products: An In-Depth Analysis of Their Composition, Bioactive Properties, and Determining Factors

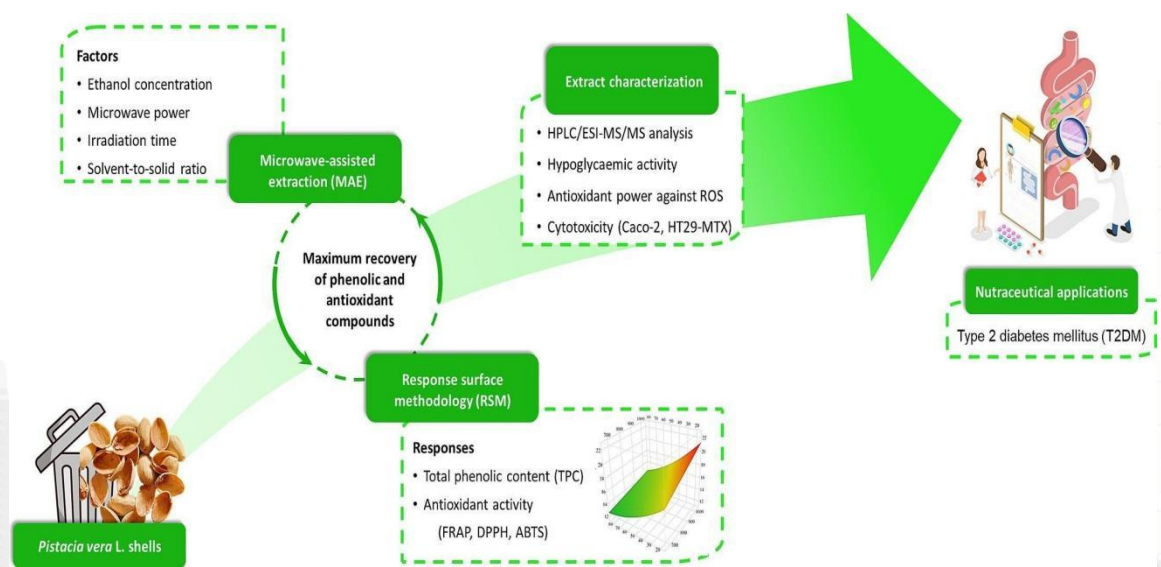


Figure 7. Bioactive compounds in pistachio by-products.

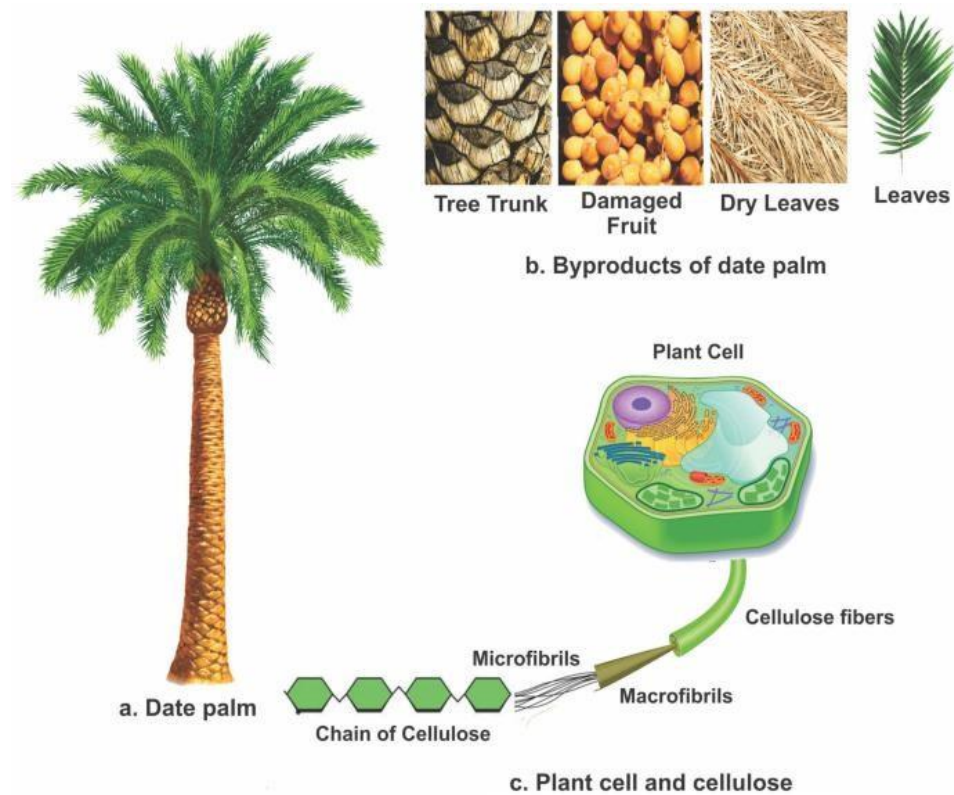


Figure 8. Bioactive compounds in palm by-products.

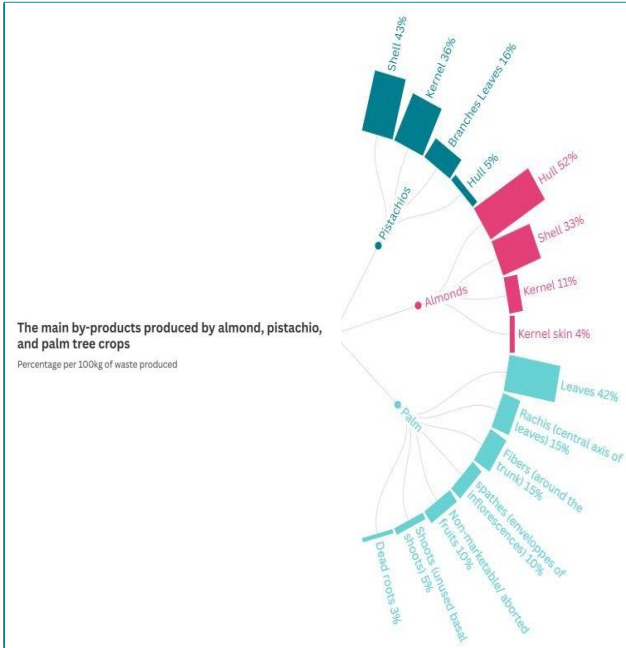


Figure 9. Estimation of quantities of by-products regenerated from almonds, pistachios and palm fruit.

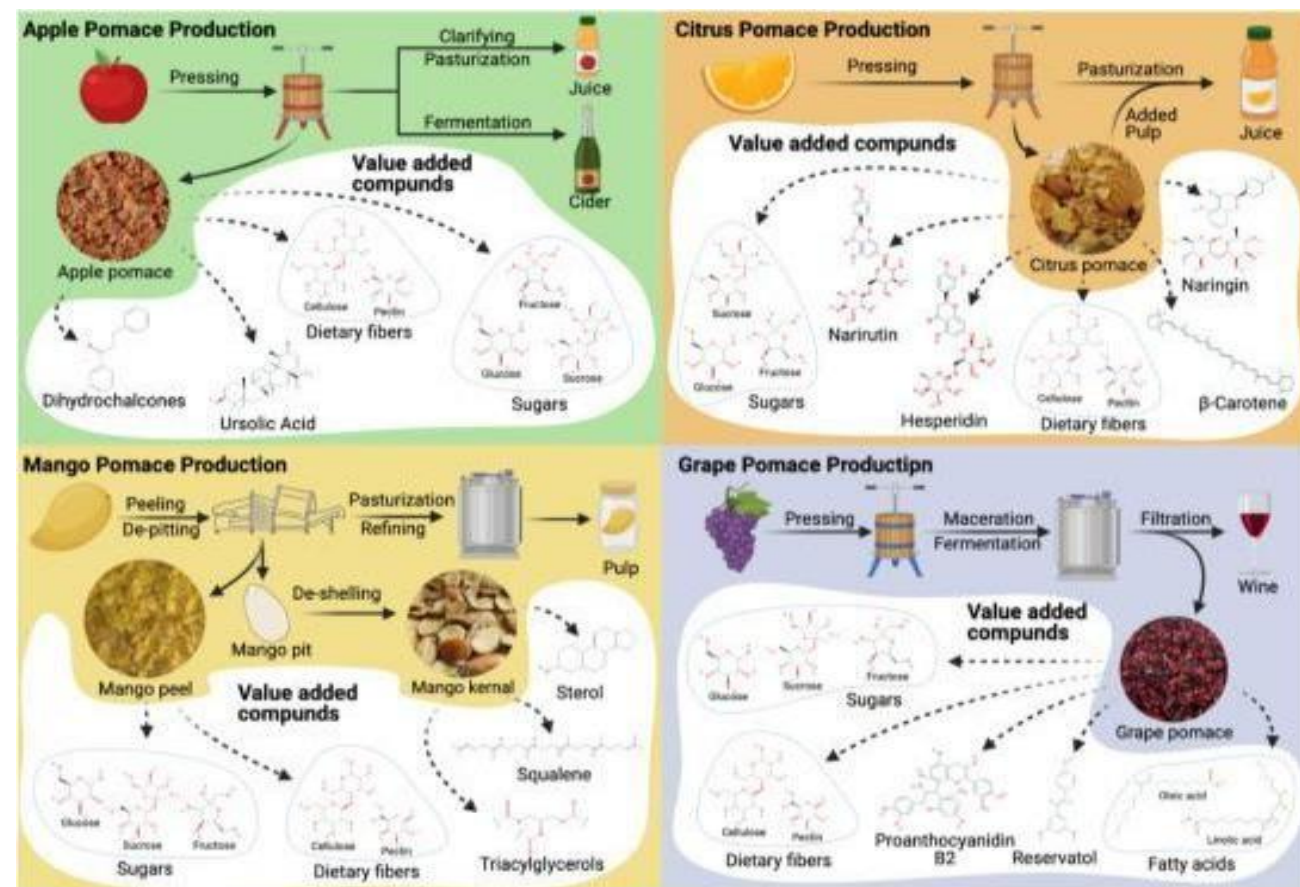


Figure 10. Valorisation pathways of fruit pomaces: Processing, Bioactive Compounds and Value-Added Products

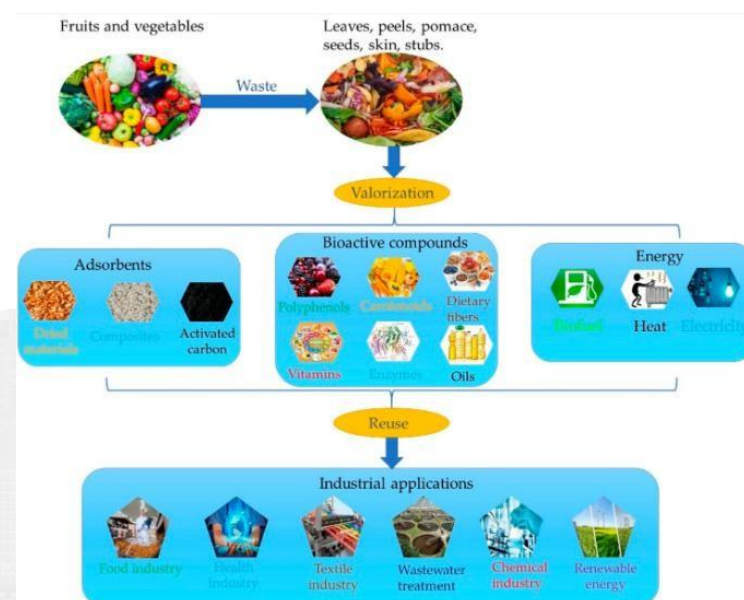


Figure 11. Conversion of fruits and vegetables waste into sustainable and value-added materials

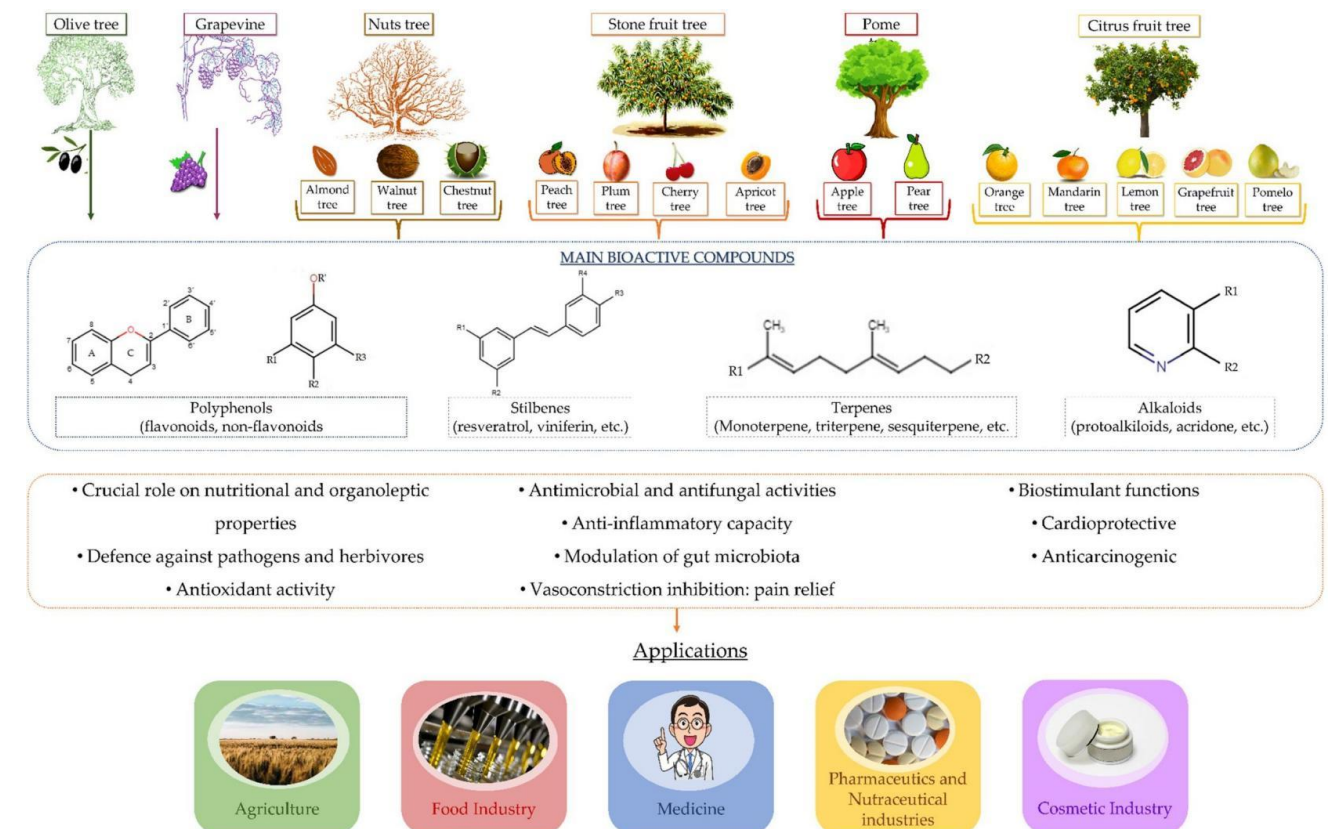


Figure 12. Bioactive Compounds from Mediterranean Fruit Trees: Functions and Industrial Applications.

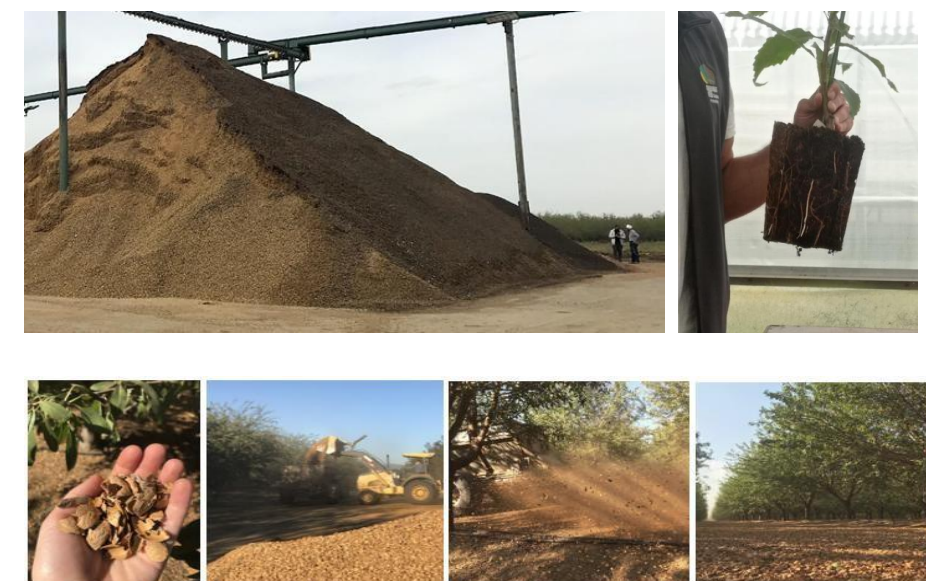


Figure 13. The agronomic potential of tree nut shells

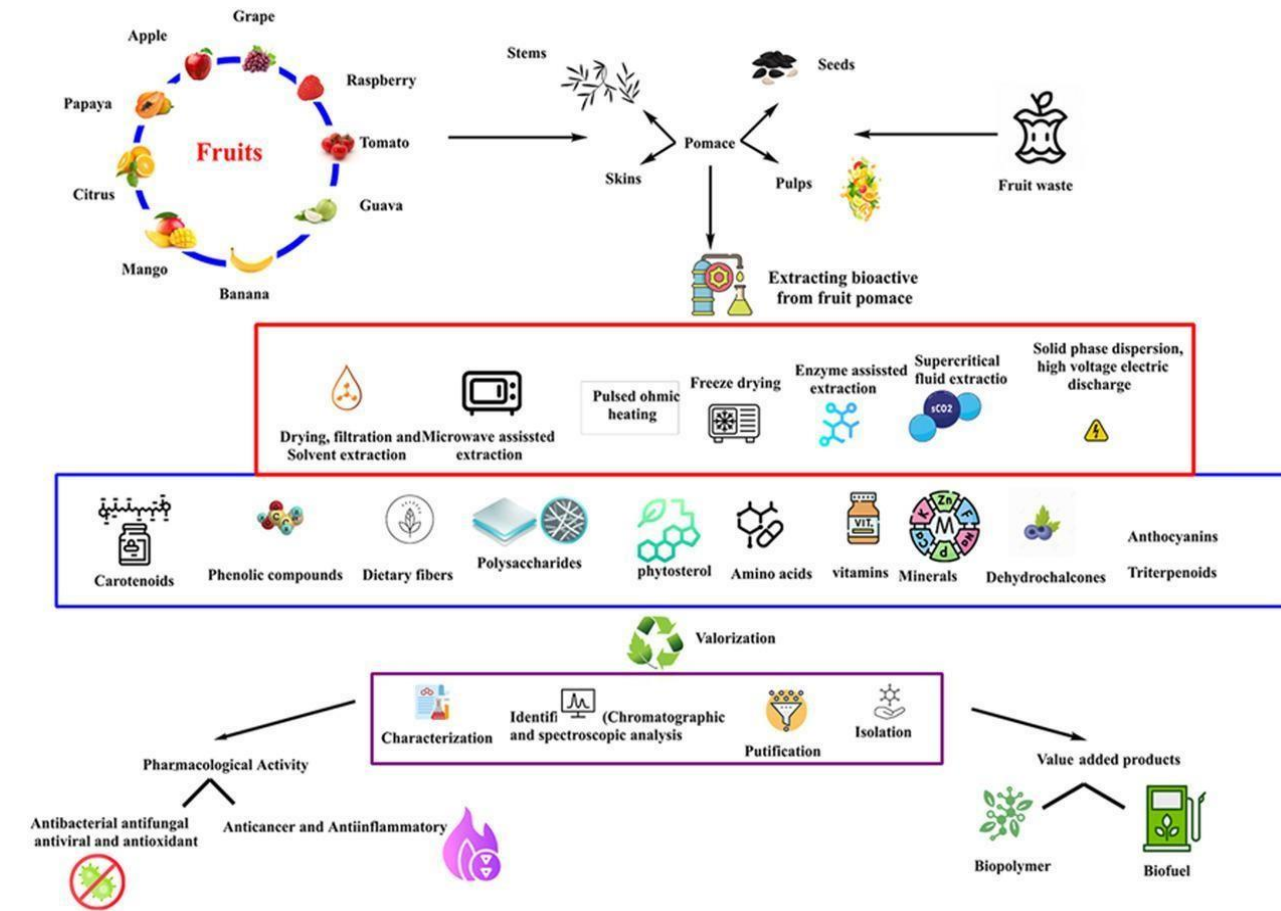


Figure 14. The potential of arboricultural by-products in various sectors

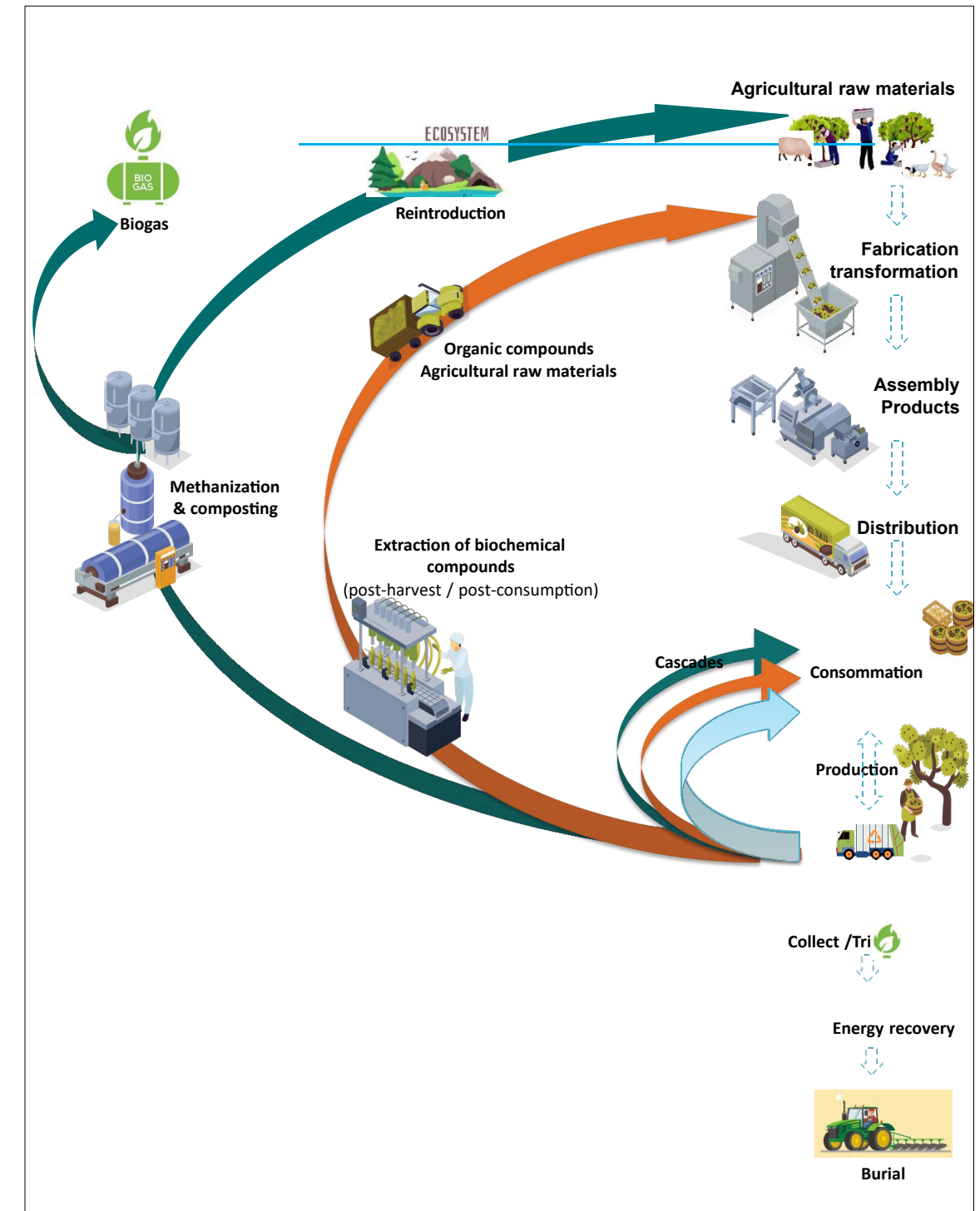


Figure 15. Natural gravel made from fruit stone shells, suitable for mulching, graveling garage driveways, parking areas, pedestrian walkways in parks and gardens, as well as playground spaces.



Figure 16. Key stages of the circular economy value chain

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