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Sustainable Supply Chains for Bioeconomy: A Survey on Projects and Literature on Agro-Biomass

Biyoekonomi İçin Sürdürülebilir Tedarik Zincirleri: Tarımsal Biyokütle ile İlgili Projeler ve Literatür Üzerine Bir Araştırma

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Abstract

Bioeconomy, which is based on the replacement of materials and energy production based on fossil resources with biomaterials and/or biofuels or energy generation from biomass resources, has an important place in the circular economy. Sustainable supply chains are essential to meet bioeconomy's full potential. This study aimed to provide a theoretical framework to make use of the untapped biomass potential in Turkey. Study focused on the literature fit for purpose for the further studies to be executed for building a holistic approach on developing biomass and bioenergy projects, alternative concepts and business models utilizing agro-biomass resources and developing a conceptual framework for sustainable supply chains for a circular bioeconomy. Research clearly shows that many projects are executed within the scope of bioeconomy in Europe, mostly with a collaborative sense, and are supported by funding mechanisms in line with EU policies. In Turkey, more regulatory policies should be developed, awareness should be raised, and application-oriented innovation projects should be developed, involving all sector stakeholders.

Keywords: Circular Economy, Bioeconomy, Bioenergy, Biomass Supply Chains, Agricultural Residues.

Öz

Fosil kaynaklara dayalı malzemelerin biyomateryaller ile, enerji üretiminin ise biyoyakıtlarla veya biyokütle kaynaklarından direkt enerji üretilmesi ile ikame edilmesine dayanan biyoekonomi, döngüsel ekonomide önemli bir yere sahiptir. Biyoekonominin potansiyelinden tam olarak faydalanabilmek için sürdürülebilir tedarik zincirleri gereklidir. Bu çalışma, Türkiye'deki kullanılmayan biyokütle potansiyelinden yararlanabilmek için teorik bir çerçeve sunmayı amaçlamıştır. Biyokütle ve biyoenerji projeleri, alternatif konseptler ve tarımsal biyokütle kaynaklarından yararlanan iş modelleri geliştirmeye yönelik bütünsel bir yaklaşımla yürütülecek gelecekteki çalışmalar için amaca uygun literatüre odaklanılmış ve döngüsel bir biyoekonomi için gerekli olan sürdürülebilir tedarik zincirleri için kavramsal bir çerçevenin geliştirilmesi hedeflenmiştir. Araştırmalar, Avrupa'da biyoekonomi kapsamındaki pek çok projenin, çoğunlukla işbirlikçi bir anlayışla yürütüldüğünü ve AB politikaları doğrultusunda finansman mekanizmalarıyla desteklendiğini açıkça göstermektedir. Türkiye'de de benzer şekilde daha fazla düzenleyici politika geliştirilmeli, farkındalık artırılmalı ve tüm sektör paydaşlarını içeren uygulamaya yönelik inovasyon projeleri geliştirilmelidir.

Anahtar Kelimeler: Döngüsel Ekonomi, Biyoekonomi, Biyoenerji, Biyokütle Tedarik Zincirleri, Tarımsal Kalıntılar.

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1. INTRODUCTION

Issues such as tackling climate change, the supply chains broken by the pandemic, the paradigm shift from globalization to localization, and the ability to supply cheap and clean energy resources considering supply security and geopolitical developments, leave their mark on our day globally. In order to overcome these challenges and achieve sustainable development goals, it is essential to switch from the linear economy model in the past, which can be summarized as take-make-consume-dispose, to a circular economy model that uses resources in a more efficient and environmentally friendly way. This requires a redesign of value chains and fundamental changes in business models and policies.

Bioeconomy, which is based on the replacement of materials and energy production based on fossil resources with biomaterials and/or biofuels or energy generation from biomass resources, has an important place in the circular economy. For effective bioeconomy deployment, supply chains must first be structured and optimized.

This study aims to provide a theoretical framework to make use of the untapped biomass potential in Turkey and pave the way for a sustainable bio-based economy and has been limited to biomass resources based on agricultural residues and agro-industry waste streams for being able to conceptualize an agro-biomass business in Turkey.

In the first section, a survey on EU funded projects for the utilization of agricultural residues as bio commodities or biofuels to substitute fossil-based materials or fuels has been conducted. Second section includes a survey on literature for designing sustainable biomass supply chains which is essential for biomaterial utilization and/or energy generation from agricultural biomass and a stepping stone for the successful application of the projects for a successful bioeconomy.

1.1. Background & Overview

Currently two global transformations are leading the way to sustainable development. First is the transition from linear economy to circular economy, second is the energy transformation promoting decarbonization, digitalization, distributed energy generation and energy efficiency. The question now is "how to convert the resources to more efficient and sustainable products and services" rather than "what sources we should use?".

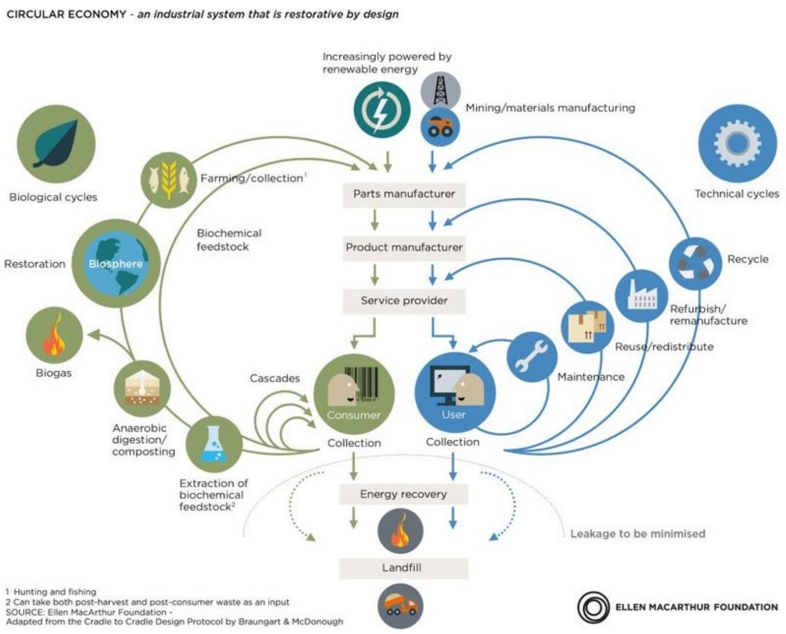

Figure 1*. The Butterfly Diagram Visualizing the Circular Economy*

The circular economy has become evident as a practical alternative to the existing linear (take-make-waste) status quo which is unsustainable and one of the global challenges of 21st century. Circular economy tends to keep resources functioning at their highest potential by means of not consuming them but recovering in a continuous and long lasting loop. The value of the resources are preserved through cycles of reusing, repairing, remanufacturing or recycling. It is a regenerative system where the needs of the public are met within the natural means (Van Kruchten et al., 2020).

Ellen Macarthur Foundation is an international charity, which was launched in 2010 and is pioneering in accelerating the transition to the circular economy. They point out that eliminating waste and pollution, circulating products and materials at their highest value and regenerating nature are the three principles which are guiding the transition to circular economy (Ellen Macarthur Foundation, 2013).

An illustration of material flows in circular economy including the two main cycles – the technical cycle and the biological cycle is presented in Figure 1, which is called as the circular economy system diagram and also known as the butterfly diagram (Ellen Macarthur Foundation, 2022).

Figure 2*. 17 UN Sustainable Development Goals*

Currently, either for academic or for industrial purposes, individual or corporate goals should be aligned with that of United Nations' 17 Sustainable Development Goals (SDGs) which are briefly illustrated in the chart provided in Figure 2. UN conceive the SGDs as "the blueprint to achieve a better and more sustainable future for all, which address the global challenges" (United Nations, 2022).

What is the relation between circular economy and sustainability? and how circular economy can help us in achieving the sustainable development goals? are the two questions which come to mind. We can simply answer them that circularity contributes to a more sustainable world, but not all sustainability initiatives contribute to circularity.

There are several studies which briefly explain how circularity is incorporated in the Sustainable Development Goals of the United Nations. One of the recent studies is on the relevance of circular economy practices to the SDGs, which provides an extensive matching exercise and an assessment of the contribution of circular economy practices to SDG goals. According to the study, circular economy practices which directly contribute to achieving SDG goals with the strongest relationships and creating synergies are stated as SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG12 (Responsible Consumption and Production) and SDG 15 (Life on Land) (Schroeder et al., 2019).

1.2. Terms & Definitions

Biomass, Bioenergy and Bioeconomy

In the Directive 2009/28/EC of the European Union, biomass is considered as one of the renewable energy sources; it is defined as "biodegradable products, wastes and residues of biological origin and biodegradable products belonging to agriculture, forestry and related industries (such as fisheries, aquaculture) and biodegradable parts of industrial and municipal wastes" (European Commission, 2009). Biomass energy is generated by valorization of biomass sources through various conversion technologies and processes and serve three main areas; electricity, heat, and biofuel production, which is mainly used for transportation.

Bioeconomy or biobased economy is a new model for industry and the economy. According to the definition of the German Bioeconomy Council (Bioökonomierat), bioeconomy is "the knowledge-based production and use of biological resources to provide products, processes, and services in all economic sectors within the frame of a sustainable economic system" (German Bioeconomy Council, 2022). It involves using renewable biological resources sustainably to produce food, energy, and industrial goods. It also exploits the untapped potential stored within millions of tons of biological waste and residual materials. The transition from a fossil fuel-based to a biobased economy is expected to reduce our dependency on fossil fuels and achieve more sustainability as well as contribute to climate and environmental protection. The 2018 EU Bioeconomy Strategy defines the bioeconomy as, "those parts of the economy that use renewable biological resources from land and sea – such as crops, forests, fish, animals and micro-organisms – to produce food, materials and energy" and strongly emphasizes that the European bioeconomy needs to have sustainability and circularity at its heart for success (European Commission, 2018).

According to a study in Universitat Autònoma de Barcelona, "circular economy is the 'what' – the result to be achieved (the desirable outcome capable of decoupling the use of resources from natural resources), whereas bioeconomy is the 'how' (what type of biophysical processes should be enhanced to achieve the expected result)". The study also indicates that the principles of a sustainable bioeconomy and the principles of a circular economy should be in harmony for proper implementation (Giampietro, M., 2019).

Developing a stronger bioeconomy will help the EU in accelerating progress towards a circular and low-carbon economy. It will also help modernizing and strengthening the EU industrial base, creating new value chains and greener, more cost-effective industrial processes, while protecting biodiversity and the environment" (European Commission, 2018).

Circular bioeconomy has enormous potential for creating millions of green jobs, especially in rural areas, creating mitigation and carbon neutrality, reducing atmospheric emissions and our dependence on fossil resources. It also helps ecosystem and biodiversity restoration, aligned with the SDGs, recover part of the degraded ecosystems. More information about the EU's bioeconomy strategy and action plan can be seen in Bioeconomy: The European Way to Use Our Natural Resources, Action Plan 2018 (European Commission, 2019).

Biomass Value Chain

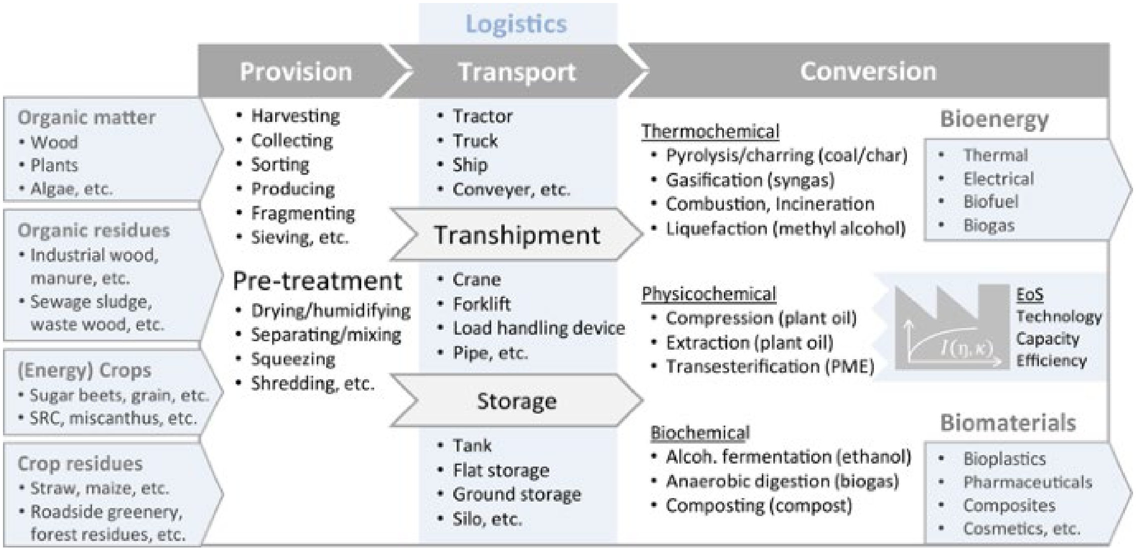

Figure 3. *Biomass Value Chain (Rudi et al., 2017)*

Bioeconomy aims at using sustainable renewable biomass resources for the production of bioenergy and various pathways exist for bioenergy generation, as illustrated in Figure 3. A general biomass value chain (BVC), also referred to as biomass supply chain (BSC) in literature, is characterized by the valorization of biomass feedstock, such as organic, wood, and crop material or residues, as well as of municipal organic wastes and manure for the production of bioenergy and innovative bio-based materials. The flow diagram given in Figure 3 illustrates the paths and interactions where biomass resources are subject to several provision and transport means and then are processed with different conversion technologies yielding various bio-products for different end-uses.

It is critical to decide which technology to apply prior to designing the biomass value chain (BVC) depending on the various biomass pathways and conversion options. The technoeconomic assessment of biomass valorization pathways is difficult and has to be supported by optimization models considering the complexity and interdependencies, such as economies of scale. Diverse BVC optimization models exist for the techno-economic assessment of biomass pathways and the selection of biomass feedstocks and technologies, which considers not only technology and capacity planning but also the trade-off between transportation costs and technology investment (Rudi et al., 2017).

Agro-biomass (Agricultural Biomass)

Biomass is derived from organic material such as trees, plants, and agricultural and urban waste. Biogas, biodiesel, and bioethanol are the three main categories of bioenergy provided by agriculture, and each has experienced dynamic growth in recent years.

In addition, short rotation coppice provides solid biomass, while agriculture also provides by-products and residues (such as straw) used for bioheat and biopower. Furthermore, dedicated energy crops like perennial grasses and short rotation forestry and coppice provide non-food cellulosic and ligno-cellulosic biomass.

Biomass grasses, short rotation forestry and short rotation coppice have high energy yields – about three times those of traditional energy crops. They imply lower environmental pressure and can be irrigated with wastewater (European Commission, 2022).

Table 1. *Agro-biomass Resources (Bioenergy Europe, 2022)*

Agricultural Residues	Large potential, 1 ton of an agricultural product yields 1 ton of agricultural residues Herbaceous: Straw, maize residues Woody: agricultural prunings, orchard plantation removals		
Agro-industrial	No harvesting required, often low moisture / good calorific value, very comptetive fuel sources Olive stones / olive cake, nut shells, sunflower husk, peach kernels, cotton ginning residues and others		
Perennial Energy Crops	Higher yields, cultivation on abondoned, marginal or contaminated land, eco-system services, etc. Herbaceous: Mischantus, switchgrass Woody / Short Rotation Coppice: poplar, willow, etc.		

With around 20% of the bioenergy feedstock coming from agriculture, both dedicated energy crops and agricultural residues can be utilized to produce heat, electricity and biofuels. Agricultural biomass represents an important and sustainable energy source although its potential remains largely untapped. Scarce mobilisation of residues is at the basis of their underutilisation. Several studies point in the direction of an increased role for agricultural biomass to achieve Europe's long-term decarbonisation objectives.

The challenges that may be encountered while developing new business models based on agricultural residues and the potential solutions to overcome these difficulties and the social and environmental benefits that can be obtained from such business models are presented in Table 2 and Table 3.

Table 2. *Benefits from Agro-biomass (Bioenergy Europe, 2022)*

Socio-Economic Benefits
Income/activity diversification for farmers
Local job creation and socio-economic development
Self-sufficiency (reduced reliance on imported fossil fuels)
Environmental Benefits
Reduction of air emissions from avoidance of open field burning of residues
Reduction of GHG emissions from substitution of fossil fuels
For lignocellulosic crops: phytoremediation, improvement of soil quality, carbon sequestration, water quality and biodiversity

Table 3. *Challenges in Agro-biomass Business (Bioenergy Europe, 2022)*

Challenges	Potential Solutions
Higher CAPEX investment requirements compared to fossil fuel options	Adopt agro-biomass heating in end-users with higher demand Subsidize CAPEX through suitable policy instruments
Dispersed resource, harvesting costs, low density	Development of local supply chains with appropriate technical implements
Challenging chemical fuel properties (e.g. ash, nitrogen, alkalis, etc.)	Use of appropriate, modern combustion technologies
Inhomogeneous material & low density	Use of appropriate feeding systems Homogenization through pelletization

Low priority of residue management for farmers	Introduction of suitable policy instruments (e.g. incentives for treatment, stricter fines for field burning)
Low priority / lack of awareness for policy makers, etc.	Knowledge transfer, dissemination, promotion of success cases

2. METHODOLOGY

This study aimed to focus not only the research papers on this subject, but also the research projects which provide a working environment and forms a base for many individual and collaborative papers and publications. The scope of this study is limited to agricultural residues and agro- industry residues, co-products and waste streams in terms of biomass sources.

A systematic literature study has not been conducted. Instead, focused on the literature fit for purpose for the further studies to be executed by the authors for:

- Building a holistic approach on developing biomass energy projects utilizing agro-biomass resources,
- Understanding alternative concepts and business models in biomass and developing a conceptual framework for sustainable supply chains for circular biomass and bioenergy projects.

A selection of exemplary projects and articles on the design of sustainable supply chains in order to form an infrastructure for new biomass energy projects or for studies on obtaining biomaterials from biomass wastes within the framework of circular economy principles in Turkey have been examined with the motivation of raising awareness in Turkey about the studies in this field.

In certain cases, project-based studies come to the prominence instead of individual studies in order to produce solutions to the major problems and needs of the European Union when research requires a more global perspective. Such collaborative research projects, particularly supported by EU funds (e.g., Horizon and similar programs) have prevailed over the past decades and researchers are required to work across disciplines, institutions and borders. Researchers can maximize outputs, answer bigger and more complex scientific questions and expand their research by combining expertise and resources. Collaborative research projects have more significant outcomes (i.e., economically viable) than independent research work and provide more opportunities to researchers from non-academic sources. (Springer Nature, 2022).

Generating outputs that have an impact on policy, practice, industry, or the general public can increase chances of getting funded. In addition, some funding bodies now give priority to international and industry-academia collaborations. For example, the EU Commission’s Horizon 2020 program, which offered nearly 80 billion Euros of funding between 2014 and 2020 for research projects tackling societal challenges, prioritized collaborative projects.

Working collaboratively can help researchers meet potential future employers, mentors, and collaborators, expanding their network. Collaborations are opportunities to learn new skills, make new friends, gain a new perspective, and join stimulating discussions and with experts in researchers’ own field or complementary fields.

From this point of view, in the first part of the study, projects supported by the Horizon program or similar funding mechanisms throughout the EU were reviewed. The projects in subject are mostly on agro-biomass. A few projects on other biomass resources, which present inspiring implementations of logistics and supply chain models like integrated biomass logistics centers and trade centers have also been surveyed. Besides, a special emphasis has been given to projects solely on developing supply chain and logistics optimization models and toolsets and setting up unique business models.

In the second and last part of this study, individual academic studies and academic publications/articles derived from the projects discussed in the first part are surveyed and a summary of literature review has been compiled with this respect, focusing on supply chain design for agricultural residues.

2.1. Review of Projects on Agro-biomass

The Circular Bio-based Europe Joint Undertaking (CBE JU) is a €2 billion partnership between the European Union and the Bio-based Industries Consortium (BIC) that funds projects advancing competitive circular bio-based industries in Europe. CBE JU is operating under the rules of Horizon Europe, the EU's research and innovation program, for the 2021-2031 period (Circular Bio-based Europe Joint Undertaking, 2022).

The Bio-based Industries (BBI) is dedicated to realizing the European bioeconomy potential, turning biological residues and wastes into greener everyday products through innovative technologies and biorefineries, which are at the heart of the bioeconomy. The BBI is about bridging key sectors, creating new value chains and producing a range of innovative bio-based products to ultimately form a new bio-based community and economy (Bio-based Industries Consortium (BIC), 2022).

BBI aims at a sustainable and competitive bio-based industry providing jobs and growth that contribute to a circular bio-society, involving primary sectors as strategic partners in bio-based value chains. BBI stimulates investment & create new, local value chains by connecting European regions and the bio-based industry and aims to establish climate-neutral operations and replace fossil-based products to mitigate climate change.

Common objectives of the BBI funded projects and expected impacts are summarized as follows:

- Building new value chains based on the development of sustainable biomass collection and supply systems with increased productivity and improved utilization of biomass feedstock (incl. co- and by-products).
- Unlocking the utilization and valorization of waste and lignocellulosic biomass.
- Bringing existing value chains to new levels, through optimized uses of feedstock and industrial side-streams while offering innovative added value products to the market, thus creating a market pull and reinforcing the competitiveness of EU agriculture and forest-based industries.
- Bringing technology to maturity through research and innovation, by upgrading and building demonstration and flagship biorefineries that will process the biomass into a range of innovative bio-based products.

Projects solely on developing supply chain and logistics optimization models and setting up unique business models in biomass are summarized in Table 4.

Project landscape as per the biomass type, project focus and the target regions are briefly presented in Table 5 which is derived from a presentation on "Lessons Learned from Earlier Projects" from Market Uptake Support for Intermediate Bioenergy Carriers (MUSIC) Project (Voset al., 2020). More information can be accessed through Bio-Based Industries Joint Undertaking website at Projects section (Bio-based Industries Consortium (BIC), 2022). Summary of the projects, objectives, expected impacts, project achievements, targeted value chains and markets and a list of consortium partners can be accessed through that portal.

Project deliverables including dissemination, communication and exploitation reports, scientific publications, roadmaps, handbooks, best practice guidelines, benchmarks, case studies, training materials, technical reports and feasibility reports can be accessed on each project's specific web site.

***Table 4**. A Summary of Optimization & Business Models on Agro-biomass with Exceptional Logistics & Supply Chain Features*

S2Biom	The main objective is to support the sustainable delivery of non-food biomass feedstock at local, regional and pan European level through developing strategies, and roadmaps that are supported by a computerized toolset with updated harmonized datasets at local, regional, national and pan European level for EU28, Western Balkans, Moldova, Turkey, and Ukraine (S2Biom Project, 2016).
euro pruning	EuroPruning aimed to optimise biomass from pruning logistics chain to make it cost-effective and to ensure quality adequacy to final consumer needs. EuroPruning developed new machinery for harvesting and treating prunings from the field, investigated solutions for cost-effective storage options, and developed a decision-support tool for improving logistics from farm to final user (EuroPruning Project, 2016).
SecureChain sustainable biomass energy	A renewable energy project supported by the European Union's research and innovation programme. The main goal is to promote sustainable bioenergy chains in the rural area, which fulfil high environmental standards and are economically viable for small and medium-sized enterprises (SME) (Kies, U., Reumerman P. et al., 2018).
sucellog	SUCELLOG aims to widespread the participation of the agrarian sector in the sustainable supply of solid biofuels in Europe. The focus is on the implementation of agro-industry logistic centres in the agro-industry as a complement to their usual activity evidencing the large synergy existing between the agro- economy and the bioeconomy (Sucellog Project, 2017).
AGRO in LOG INTEGRATED BIOMASS LOGISTICS CENTRES FOR THE AGRO-INDUSTRY	The main goal is the demonstration of Integrated Biomass Logistic Centres (IBLC) for food and non-food products, evaluating their technical, environmental and economic feasibility. The project is based on three agro-industries that are willing to deploy new business lines in their facilities to open new markets in bio-commodities (energy, transport and manufacturing purposes) and intermediate bio-products (transport and biochemicals) (AgroInLog Project, 2022).
NREL Transforming ENERGY (IBSAL)	The Integrated Biomass Supply & Logistics (IBSAL) model is a dynamic (time dependent) model of operations that involve collection, harvest, storage, preprocessing, and transportation of feedstock for use at a biorefinery. The model calculates itemized costs, energy input, and carbon emissions. It estimates resource requirements and operational characteristics of the entire supply infrastructure (The National Renewable Energy Laboratory (NREL), 2022)

Table 5. *A Summary of Projects on Agro-biomass in EU (Vos et al., 2020) & (Bio-based Industries Consortium (BIC), 2022)*

	Biomass Type				Project Focus					Target Countries			
Project Name	Forest Biomass	Agro-biomass	Landscape Biomass	Marginal Lands/Energy Crops	Biomass Mapping	Mobilisation of Biomass	Value Chain Development	Logistics Develeopment	Logistics& Trade Centers	South EU	North EU	Central EU	East EU
AgroBioHeat		x		x			x			x			
AgroInLoG		x							x	x	x		
BioBoost	x	x	x		x	x		x		x	x	x	x
BiomasSud +		x			x					x			
Bio4A				x			x			x			
TradeCenter II	x								x				x
BioPlat-EU				x			x			x	x	x	x
BioRes	x								x				x
EuroPruning		x				x		x		x		x	
Enabling	x	x	x	x		x	x		x	x	x	x	x
ForBio				x	x		x			x		x	x
GreenGain			x		x	x	x			x		x	
Infres	x				x			x			x	x	
Logist'EC				x		x	x	x		x		x	
S2BIOM	x	x	x	x	x			x		x	x	x	x
SecureChain	x						x			x		x	
SimWood	x					x				x	x	x	x
SucelLog		x							x	x		x	
uP_running		x	x		x	x	x			x		x	

2.2. Biomass Supply Chain Design & Decision Variables

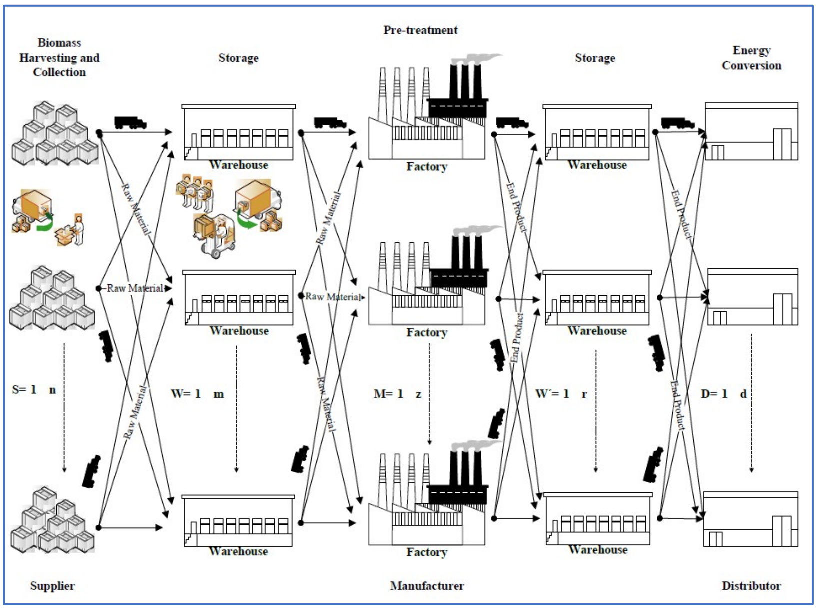

Figure 4. *Biomass Supply Chain Network (Zahraee, S.M., Shiwakoti, N., Stasinopoulos, P., 2020)*

Biomass supply chain management and optimization studies apply to network design problem within conversion, storage and transportation, scheduling problem within harvesting & collection, storage and transportation, facility location problem within pretreatment, storage and conversion, vehicle routing problem within harvesting, collection and transportation and lastly technology selection problem within pretreatment and conversion (Sun et al., 2020). Performance evaluation and optimization models are the two main approaches used in network modeling in biomass supply chain design. These models are classified into three sub-models in each; models based on cost calculations, GIS-based models and simulation models in performance evaluation whereas deterministic, stochastic and multi-objective models in optimization (Ba et al., 2016).

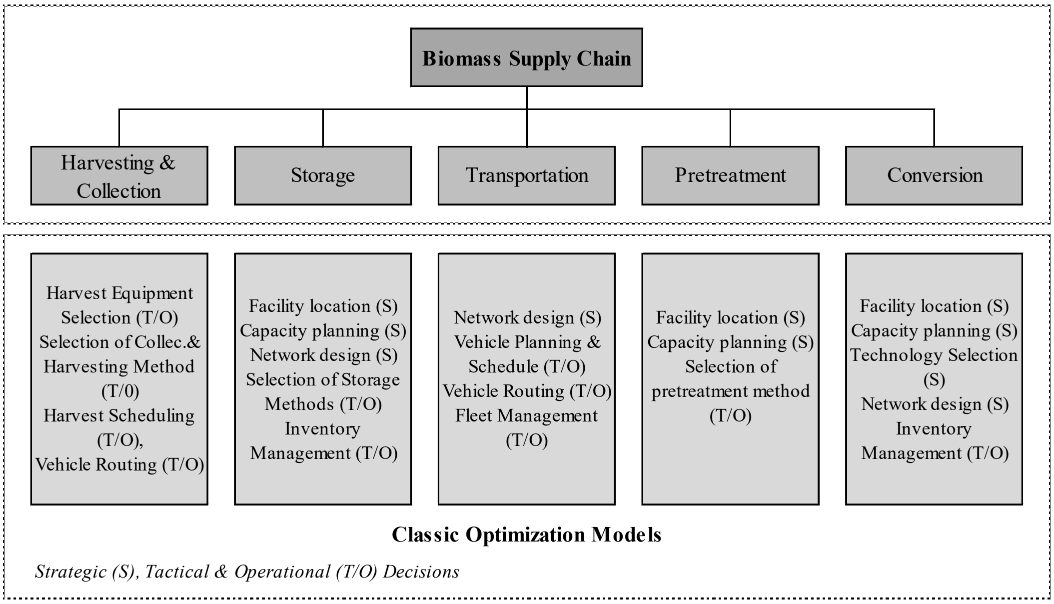

Figure 5. *Strategic, Tactical & Operational Decisions in BVC Design*

Strategic, tactical, and operational decisions are made based on different decision variables while designing a biomass value chain. It is seen that most of the research has focused on strategic and tactical decisions (Ba et al., 2016).

Strategic decisions comprise decisions valid for long-term periods which require substantial financial investment. While developing bioenergy projects, such decisions cover the selection of biomass types, the size and location of pretreatment plants and conversion equipment, the transportation modes, and making long-term supply contracts. Tactical decisions include medium-term decisions which are applied for a multi-period time span, over a few months. Examples in biomass supply chains cover the harvesting amount in each period for each farm/land, the number of vehicles required (fleet size), and the safety stock levels. Finally, operational decisions are made for a short-term, usually over a few days. They are derived from splitting tactical decisions into detailed operations. The timing of harvesting operations in a given day and the assignment of detailed vehicle routes are typical examples in biomass supply chains (Zahraee et al., 2020).

Unlike fossil resources, biomass is spatially distributed and its valorization is restricted by low-energy densities and high water contents. Long-distance transportation is not cost-effective, as a result of which small- or medium-scale conversion facilities are required. Large scale facilities, on the other hand, benefit from economies of scale and lower specific investments. For this reason, a trade-off between transportation and investment-related cost exists, which affects the structure of the biomass value chain (Rudi. et al., 2017).

In the second and last part of this study, individual academic studies and academic publications/articles derived from the projects discussed in the first part are surveyed and a summary of literature review has been compiled with this respect, focusing on supply chain design for agricultural residues.

Table 6 presents a summary of literature on selected topics focusing on supply chain design for agricultural residues and agro-industry waste streams. The scope of the literature reviewed is comprehensive to provide the readers a wide perspective on developing sustainable supply chains on agro-biomass including literature and market reviews, field and case studies, research reports by institutions, techno-economic assessments, conceptual framework and business models, GIS-based models, simulation models and optimization models.

***Table 6**. Literature Review Summary for Selected Topics in Agro-biomass*

No	Authors & Date	Problem	Methodology	Summary
1	Balaman Ş.Y., 2014	A Fuzzy Goal Programming Based Decision Support System for Design and Management of Biomass to Energy Supply Chains	Design-oriented research, mathematical modeling	A fuzzy goal programming-based decision support system for bioenergy supply chain planning with a holistic view and simultaneous provision of economic and environmental objectives and service level targets for a comprehensive SCT, and for addressing the uncertainties in the target values of parameters and decision makers.
2	Athanasios, A.R. et al., 2009	Logistics issues of biomass: The storage problem and the multi-biomass supply chain	Analysis, case study	Applying a case study of three commonly used biomass storage methods to achieve concrete comparative results and develop an innovative model to reduce storage space requirement by combining multiple biomass supply chains
3	Tatsiopoulos, I. & Tolis, A., 2003	Economic aspects of the cotton-stalk biomass logistics and comparison of supply chain methods	Optimization, simulation	This paper describes a model, which simulates the cotton biomass supply chain. This study examines the feasibility and the problems that arise while trying to organize an integrated logistics network and optimize its transportation economy. Also, economic aspects of other logistics procedures like collection and warehousing are analyzed.
4	Devrim, M.Y., Van Duren, I. et al., 2016	Design of sustainable second-generation biomass supply chains	Analytical model, case study	Comparison of the economic and environmental impacts of supply chain applications in 4 different scenarios for the evaluation of second-generation biomass resources for energy production in centralized, decentralized and mobile energy conversion facilities.
5	Lautala, P., Hilliard, M. et al., 2015	Opportunities and Challenges in the Design and Analysis of Biomass Supply Chains	Conceptual framework, simulation, literature review	Concept study including integrated supply systems for sustainable biomass trade and alternative models for investigating the factors affecting the biomass supply chain.
6	Khwaja, C. et al., 2015	Triggering the creation of biomass logistic centres by the agro-industry	Case study, application	It is within the scope of the SUCELLOG project to expand the agricultural sector's participation in sustainable biomass supply. The project is to be used as biomass logistics centers where agricultural and agricultural industry wastes and residues are processed and handled during the idle periods of the agro-industrial establishments, which are complementary to their usual activities. Identification of companies that are suitable for this project.
7	Sambra, A. & Sørensen, C., 2008	Optimized Harvest and Logistics for Biomass Supply Chain	Benchmark, Case study	Research within the scope of the BioREF (sustainable, reliable and economical production of fuel from energy crops in bio-refineries) project. Optimization of harvesting and logistics for the transport of oilseed crops and suitable agricultural residues to production facilities & reverse logistics of process residues for agricultural use in the biomass feedstock infrastructure.
8	Aalto, M., Korpinen, O. et al., 2017	Dynamic Simulation of Bioenergy Facility Locations with Large Geographical Datasets – A Case Study in European Region	Simulation, GIS, Geographical Data Analysis	A low-cost method for the logistics of agricultural residues that considers time and location-dependent variations in biomass supply
9	Annevelink, B., Gogh, B., et al., 2017	Conceptual Description of an Integrated Biomass Logistics Centre (IBLC)	Conceptual framework	Application of integrated biomass logistics centers in agro-industrial organizations. Determining the features and characteristics of these centers, evaluating their technical, environmental and economic feasibility. Comparison of competitive advantage of agro-industry organizations according to biomass supply business models to be established from scratch (Agro-in-log is the successor to the Sucelllog project)

10	Lucile, G., Marion, D., Hélène P., 2022	Biomass Supply Chains Development in Rural Areas: How to Take Public Stakeholders' Needs and Expectations into Account?	Case study, survey & interviews, decision making support	Increasing regional integration while developing biomass supply chains in rural areas. Determining the needs and expectations of public stakeholders, presenting suggestions for regional integration accordingly, being involved in the decision-making process, determining the economic, environmental and social criteria considered in regional projects in this process.
11	Kougioumtzis, M.A., Karampinis, E. et al., 2018	Assessment of biomass resources for an integrated biomass logistics center (IBLC) operating in the olive oil sector	Field study, analytical study, case study	The use of olive pomace plants operating in the olive oil sector as IBLC, which processes olive tree pruning residues as a biomass raw material after the main post-processing, apart from their normal operations. The results of this study will also be a guide for other facilities operating in the sector.
12	Annevelink, B., Garcia Galindo, D., et al., 2017	A logistics case study with "LocaGIStics" software for the Aragon (Spain) Region	Case study, supply chain design,	LOCAGISTICS is support software specially developed for regional distribution chains. From the plans of energy and biomass producers; Better designs can be developed by considering logistics concepts such as transportation, preprocessing, storage, and energy conversion criteria.
13	Menéndez, J. A., Fernández-Tresguerres, L. et al., 2018	Report on the availability of Biomass Sources in Spain: vineyards and olive groves	Research report	Prepared for EU ERANETMED2-72-246 project. This project aims to directly use biomass waste from vineyards and olive groves for electricity generation.
14	Vourdoubas, J., 2017	Power generation possibilities from olive tree pruning residues, olive industry by-products and other wastes in Crete, Greece	Literature review, technical and economic assessment	Investigation of current use and future prospects of olive tree pruning residues, olive industry by-products and waste for energy generation in Crete. Calculation of energy production potential based on olive tree biomass estimation in Crete. Evaluation of the experiences in olive oil producing countries together with the technologies used or tried so far.
15	Pantaleo, A., Carone, M., Pellerano, A., 2012	Olive Residues to Energy Chains in the Apulia Region Part I: Biomass Potentials and Costs	Field study, analytical study, techno-economic assessment	The residue, waste and by-product sector in the olive growing value chain is reviewed. The energy potential of pruning waste and pomace is estimated and collection costs are evaluated with different supply chain scenarios.
16	Iakovou, E., Karagiannidis, A. et al., 2010	Waste biomass-to-energy supply chain management: A critical synthesis	Literature review, decision making support	A critical synthesis of the literature applicable to all stakeholders involved in the design and management of biomass supply chains is presented. General system components and the different aspects that distinguish them from traditional supply chains are discussed. The results of all relevant literature are classified. The decision-making process for biomass supply chain design is examined and these are mapped at the relevant strategic, tactical and operational levels of the hierarchy and research is classified.
17	Manzanares, P., Ruiz, E. et al., 2017	Residual biomass potential in olive tree cultivation and olive oil industry in Spain: valorization proposal in a biorefinery context	Business model proposal	Olive crop and olive oil industry generates several residues, i.e., olive tree pruning biomass (OTPB), extracted olive pomace (EOP) and olive leaves (OL) that could be used to produce high-added value products in an integrated biorefinery. OTPB is generated in the field as a result of pruning operation to remove old branches; EOP is the main residue of the pomace olive oil extracting industry after extraction with hexane of residual oil contained in olive pomace; and OL comes from the olive cleaning process carried out at olive mills, where small branches and leaves are separated by density. In this work, an analysis of the potential of OTPB, EOP and OL residues was addressed by estimating the production volumes at national level and the spatial distribution of these residues using geographic information system software.

18	Voivontas, D., Assimacopoulos, D., Koukios, E., 2001	Assessment of biomass potential for power production: a GIS based method	GIS based decision-making analysis.	A method is presented, which estimates the potential for power production from agriculture residues. A GIS decision support system (DSS) has been developed, which implements the method and provides the tools to identify the geographic distribution of the economically exploited biomass potential.
19	Sun, O., Fan, N., 2020	A Review on Optimization Methods for Biomass Supply Chain: Models and Algorithms, Sustainable Issues, and Challenges and Opportunities	Literature review, bibliometric analysis	Due to special characteristics of biomass, this particular kind of supply chain is different from the classic supply chains in different ways. The optimization methods, including mathematical programming and heuristic algorithms are widely used in the domain of biomass supply chain management in both tactical and practical manners Literatures are classified by different components throughout the entire supply chain: harvesting and collection, storage, transportation, pretreatment, and conversion. A bibliometric analysis is also performed in this review to obtain comprehensive understanding of this area.
20	Sharma, B., Ingalls, R. et al., 2013	Biomass supply chain design and analysis: Basis, overview, modeling, challenges, and future	Literature review,	Efficient supply chain management of lignocellulosic biomass is crucial for the success of second-generation biofuels. This paper systematically describes energy needs, energy targets, biofuel feedstocks, conversion processes, and finally provides a comprehensive review of Biomass Supply Chain (BSC) design and modeling. Specifically, the paper presents a detailed review of mathematical programming models developed for BSC and identifies key challenges and potential future work.
21	Rudi, A., Müller, AK., Fröhling, M. et al., 2017	Biomass Value Chain Design: A Case Study of the Upper Rhine Region	Techno-economic Assessment, Mathematical modeling, Decision-making support	A case study application of a biomass value chain design for the tri-national Upper Rhine Region is presented. A mathematical model is formulated, which uses existing potentials in order to optimize the biomass value chain in terms of multiple feedstocks, technologies, and outputs. The resulting insights provide for a techno-economic assessment of biomass value chains and the identification of potential biomass pathways.
22	Heinimö, J. & Junginger, M., 2009	Production and trading of biomass for energy – An overview of the global status	Market review	The aim of this paper is to summarize trade volumes for various biomasses used for energy and to review the challenges related to measurement of internationally traded volumes of biofuels.
23	Wu, J. & Wang, L., 2012	Economic Analysis Model for Biopower Plants Based on Biomass Logistics Networks and Its Application in Heilongjiang Province, China	Optimization, mathematical modelling, Economic feasibility	A mathematical model was developed to assess the economic feasibility of a biomass-based power plant in the Northeast of China. The objective of this model is to maximizes the net present value (NPV) of a biopower plant over its economic life, which subjects to the constraints of biomass availability, plant investment and operation & maintenance costs, plant capacity, transportation logistics, raw material and product pricing, financing, and business taxes.
24	Perpiñá Castillo, C., Alfonso, D. et al., 2009	Methodology based on Geographic Information Systems for biomass logistics and transport optimisation	GIS, Mapping, Facility Location Selection	The aim of this study is to contribute by outlining a procedure for achieving an optimal use of agricultural and forest residue biomass. In this regard, it develops and applies a methodology focused on logistics and transport strategies that can be used to locate a network of bioenergy plants around the region. This methodology was developed using a Geographic Information Systems and it provides information on the spatial distribution of biomass residues.
25	Frombo, F., Minciardi, R. et al., 2009	A decision support system for planning biomass-based energy production	Optimization, GIS, Decision Support System	Environmental decision support systems (EDSS) are recognized as valuable tools for environmental planning and management. In this paper, a geographic information system (GIS)-based EDSS for the optimal planning of forest biomass use for energy production is presented. A

				user-friendly interface allows the creation of Scenarios and the running of the developed decision and environmental models.
26	Ruiz, J., Juárez, M.C. et al., 2013	Biomass logistics: Financial & environmental costs. Case study: 2 MW electrical power plants	Techno-economic analysis	This paper examines the following points concerned with the logistics of biomass: optimum biomass transport distances to plants, transport costs, CO2 emissions relative to CO2 avoided and the surface areas required to grow or collect biomass. Particular emphasis is placed on the logistics of biomass-fired electric power plants rated at 2 MW electrical, a size that enables electric power distribution to be decentralized.
27	Alakangas, E., Wiik, C. & Vesterinen, P., 2008	Efficient trading of biomass fuels and analysis of fuel supply chains and business models for market actors by networking	Market review	Analysing the current and future biomass fuel market trends and biomass fuel prices. Additionally, collected feedback on the suitability of CEN 335 solid biofuel standard for trading of biofuels. Estimation on techno-economic potential of the biomass was given until 2010 based on the existing studies and experts' opinions.
28	Morales-Rincon, L., Martínez, A. et al., 2015	Gis-Based Methodology for Optimum Location of Biomass Extraction Plants and Power Plants Using Both Logistic Criteria and Agricultural Suitability Criteria	GIS based facility location	A GIS-based methodology to identify the optimal locations for biomass extraction plants and biomass power plants is presented. Both agricultural land suitability criteria and logistic criteria were considered to select the optimal locations. Agricultural land suitability criteria were included as several independent variables of edaphic and climate conditions.
29	Ravula, P., Grisso, R. & Cundiff, J., 2008	Cotton logistics as a model for a biomass transportation system	Discrete event simulation, Optimization	Various systems capable of harvesting, storing and transporting biomass efficiently, at a low cost, need to be designed. The transportation system of a cotton gin, which shares several key components with a biomass transportation system, was simulated using a discrete event simulation procedure, to determine the operating parameters under various management practices.

3. FINDINGS & DISCUSSION

Currently two global transformations are leading the way to sustainable development. First is the transition from linear economy to circular economy, second is the energy transformation promoting decarbonization, digitalization, distributed energy generation and energy efficiency. The question now is "how to convert the resources to more efficient and sustainable products and services" rather than "what sources we should use?". Going circular and deploying bioeconomy will help us achieve sustainable development goals and tackle climate change.

Despite the fact that energy generation from biomass has a very old history in Europe, many R&D, innovation, technology development and application projects are carried out to evaluate biomass primarily as biomaterials, in accordance with the principles of circular economy, and it is tried to increase the usage areas of biomaterials.

Although it is widely used in the European Union countries, it can be said that biomass energy is still an overlooked giant in the field of renewable energy. Many projects within the scope of bioeconomy are supported by policies and funding mechanisms. Renewable energy investments are expected to increase throughout the European Union as a result of the geopolitical risks that have reached the highest level with the Russia-Ukraine war and the supply security threats brought about by the dependence on Russian natural gas and oil. In this framework, the sector stakeholders demand the support and funds for energy production from biomass to be increased.

Studies in the European countries are generally carried out within the scope of large projects funded by the European Union, as part of the whole, in accordance with the organization and project goals and objectives. It is seen that there are fewer individual studies. The transition to a similar working culture in Turkey will be beneficial in closing our research gap on this subject.

4. CONCLUSION & IMPLICATIONS

Right policies and rigorous sustainability regulations is essential to meet bioeconomy's full potential. More regulatory policies should be developed in Turkey to foster a national strategy and standards taking both circular economy principles and energy transition into account. On the other hand, dissemination activities should be organized in order to raise awareness among the public.

Utilizing more biomass resources as biomaterials and/or biomass energy sources to replace fossil resources will facilitate transition to a circular economy and increase renewable share in the energy mix. Clear goals should be defined for an efficient bioeconomy. It seems that there is a need for an upper regulatory body that will coordinate the execution of the works within these targets and determine the necessary incentives.

Relevant legislation and incentives should support initiatives in R&D and application-oriented innovation projects, involving all sector stakeholders, especially universities and industrial organizations.

It is seen that Turkish research institutions rarely participate in European Union supported projects, but even these studies are not sufficiently announced and introduced to other sector stakeholders and relevant institutions and organizations in Turkey. More collaboration either nationwide or internationally is required for proper and efficient project execution and being able to achieve the targets.

Turkey is currently experiencing great economic difficulties. On top of that, we are experiencing great difficulties in access to agricultural products at reasonable prices on the consumer side and producers/farmers have cost issues. To overcome these problems, agricultural policies should be reorganized, and it is essential to develop a biomass economy based on agricultural residues, which will allow agricultural producers to reduce their costs and earn additional income. In this way, rural development will be possible with both additional income and new job opportunities.

Technical and economical characteristics of biomass energy projects require multidisciplinary and interdisciplinary studies. Biomass resource assessment, biomass supply chain design and management, and logistics optimization activities need to be carried out properly in order to execute efficient projects in energy generation from biomass.

Considering country conditions, current academic studies and projects for energy production from biomass, the projects and literature examined in this study will shed light on our future research and possible thesis study on the supply chain design and logistics optimization required for the use of olive pruning residues and olive oil industry residues (olive cake, pomace) in biofuel or power plant energy production. Currently, there is not such an application in Turkey.

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