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Review

Green, Yellow, and Woody Biomass Supply-Chain Management: A Review

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Abstract: Various sources of biomass contribute significantly in energy production globally given a series of constraints in its primary production. Green biomass sources (such as perennial grasses), yellow biomass sources (such as crop residues), and woody biomass sources (such as willow) represent the three pillars in biomass production by crops. In this paper, we conducted a comprehensive review on research studies targeted to advancements at biomass supply-chain management in connection to these three types of biomass sources. A framework that classifies the works in problem-based and methodology-based approaches was followed. Results show the use of modern technological means and tools in current management-related problems. From the review, it is evident that the presented up-to-date trends on biomass supply-chain management and the potential for future advanced approach applications play a crucial role on business and sustainability efficiency of biomass supply chain.

Keywords: supply-chain design; strategic planning; operational planning; energy crop production; crop residue

1. Introduction

For the generation of any product, a sequence of processes connected to design, decision making, and execution, and a series of financial, information, and material flows are performed throughout different stages of the production. The different stages of the production constitute an integrated system called supply chain. The basic aim for the successful design of a supply chain is to meet the requirements of the final customer regarding a specific product. The supply-chain concept for agri-food and biomass relates to not only manufacturing and retailing sectors but also to agricultural sector.

In recent decades, energy crops constitute a highly-potential share among crops taking into account the need for greener energy production. Energy crops are crops that are cultivated for biomass, biogas, or other biofuels (e.g., biodiesel, bioethanol) production. They are mostly green crops that come from wild nature, such as perennial grasses with high potential for bioenergy production. Green-type biomass includes crops such as *Miscanthus*, *Panicum virgatum* (also known as switchgrass), *Arundo donax*, etc. At the same level, yellow biomass refers to crop residues that come from any crop and represent another category of biomass production related to feedstock. Examples of yellow biomass are corn stover, wheat straw, etc. It should be mentioned that the main sources of biogas production are the energy crops and the use of agricultural residues [1]. On top of this, there is a variety of woody crops that contribute significantly to biomass energy production globally. Woody biomass is any biomass that is connected to wood sources. Examples of woody biomass sources are willow, poplar short-rotation coppice, etc. All of them have various and complex constraints regarding the entire management policy and practices that should be followed for the optimal biomass production.

The main challenges regarding supply chain issues on each biomass type category, as they are presented above, are different. Challenges related to green-type biomass include any grass-type crop operational issues, including particular issues in harvesting and handling (such as optimal scheduling), and less on other processes (such as soil cultivation or fertilization) due to their easy adaptability to various environments. On the other hand, yellow-type biomass requirements include optimal collection, handling and transportation processes. This incorporates on-time scheduling of collection and transportation and optimal task execution in cases where multiple fields are covered. Challenges on woody biomass sources are different from the other two types given its operational processes particularities. The woody energy crops require different crop establishment, cultivation, harvesting, and transportation processes. Of course, some operational issues would be similar with the other two types (such as scheduling of operations), but there are technical issues that are solved in different ways. A short example regarding collection and transportation would be about harvesting of green or yellow biomass in bale form compared with woody crops that whole trees are collected.

At this time, supply-chain management (SCM) in agricultural production, handling, and transportation processes is vital and there are always various issues that should be faced through better SCM. There is a large amount of research works regarding SCM of green, yellow, and woody biomasses. The work here, targets on an up-to-date literature review on recent publications on green, yellow, and woody biomass SCM.

The main challenges for the creation of this review were, firstly, to underline variation practically in different approaches for specific existing problems in SCM, secondly, to provoke the development of supply-chain management on the specific target group by proposing possible solutions on various upcoming matters and, finally, to provide a brief review of various followed practices/methodologies and their effects on the SCM.

There are previous reviews on the supply-chain management in agricultural processes regarding green, yellow, and woody biomass types. A biomass supply chain evaluation and optimization are suggested by a literature review regarding forest feedstock [2]. A systematic review was presented in order to present the key factors throughout the biomass supply chain of green and woody crops that affect the application of bioenergy buffers in complex bioenergy production systems [3]. A wider review about biofuel SCM is conducted under the objective of uncertainties and sustainability issues [4]. On the opposite side, a more practical review was presented regarding many types of mathematical models in bioenergy crops production, including both energy crops production processes and transportation but also biorefinery/biomass conversion modeling processes [5]. Even though the scientific contribution of these reviews is highly important, to the knowledge of the authors, there is no recent review regarding chain management aspects for green, yellow, and woody supply.

The objective of this paper is to highlight and focus on green, yellow, and woody biomass supply-chain management research works (52 studies), and, as a second step, to create a classification in order to propose opportunities for further research by focusing on research gaps and identified issues needed to be tackled.

2. Supply-Chain Management Definition

In order to conclude to a successful definition of SCM, i is important to make a short comparison between traditional management (TM) practices and SCM practices. Under the financial concept, by TM a reduction in a company's costs may be achieved, while by SCM a whole-chain cost efficacy will be obtained. Regarding data exchange and monitoring information, the first case is limited on the business's own needs, while in SCM it can be extended for whole-chain planning and/or monitoring processes. Another point is the coordination between different levels of a channel, where in TM there is only a single contact for the interchange among the channel pairs, while by SCM multiple contacts and coordination between various businesses and levels of channels can be accomplished. Finally, there is a number of risks and rewards that cannot be shared under the TM philosophy, but by SCM all the risks and rewards are shared in a long-term period. The above-mentioned comparison is only a small sample of the differences between TM and SCM, suggesting the need for assimilating more and more SCM practices.

There are various ways to describe and define SCM. For the purpose of this paper a definition of the term regarding crop production processes would be: Supply-chain management is the integrated planning of in-field and/or logistics operations, application of these operations, coordination between the different levels of the channel(s) and, finally, control of all processes and necessary activities in order to produce and transport, in the most efficient way, the products that finally will satisfy the requirements of a given market [6].

Given this definition, we could set that all the in-field and logistics processes are included in the term supply chain, not only as a physical operation but also as a decision-making activity, both associated by material flows and exchange data and, as a consequence, the correlated financial/energy flows. In this light, the supply chain includes not only the producer and its suppliers, but also includes the processing units, logistics operators, warehouses, etc.

3. Review Methodology

The methodology followed in this review includes a series of theoretical considerations taken into account in the pre-processing stage. Throughout our analysis, the included steps (as also presented in Figure 1) are the following:

- Step 1: Development of the review protocol in terms of the eligibility criteria considering a single published research article as the set analysis unit.
- Step 2: Search for research studies and select the ones satisfying the eligibility criteria.
- Step 3: Definition of the classification framework to be applied in the literature review in order to classify the material and build the structure. Four classes (green, yellow, woody, and multiple-type biomass) are applied here with two sub-classes (i.e., the problem-based class and the methodology/approach-based class).
- Step 4: Selection of studies to be included in each classification within the framework.
- Step 5: Analysis of the selected studies and creation of a short summary of each individual work allocated to the corresponding class.
- Step 6: Representation of results by studies comparison.

3.1. Eligibility Criteria

Studies related to green, yellow, woody, and multiple-type biomass SCM are included in this study. At the same time, as woody biomass is only referred to woody energy crops (such as willow), publications related to forest species or forest waste biomass are excluded from the scope of this review. The SCM-related tasks are included in the wide boundary in which this review's scope is subjected, as presented in Figure 2. For the scope of this study, the included publications should be related to SCM, and should be referred mainly to the crop production processes and/or the transportation from farm to the field and/or from field to the plant. Any further biomass conversion operations or processing was considered to be out of the scope of this review. However, publications that refer to individual operations and not to inter-connected parts of the supply chain were not taken into account.

A number of literature-related eligibility criteria are set. These criteria include: (1) The work should be published in English language, (2) the included studies should be research articles published in peer-review journals, and (3) they should have been published within the last five years (current one included; i.e., from 2015 up to present). Publications in journals that are not research articles, such as reviews or short communications are excluded from this review paper.

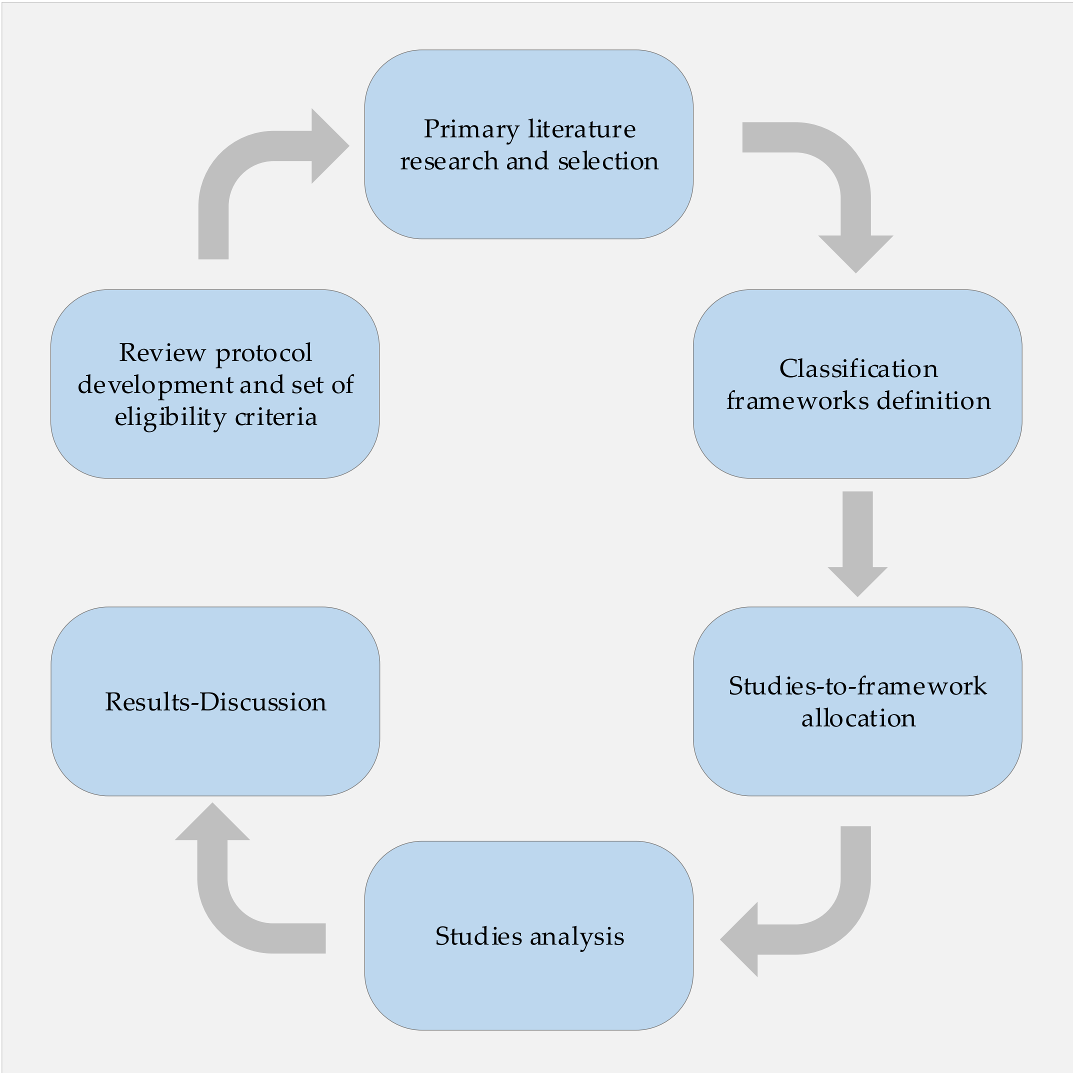

Figure 1. The summary of the review process.

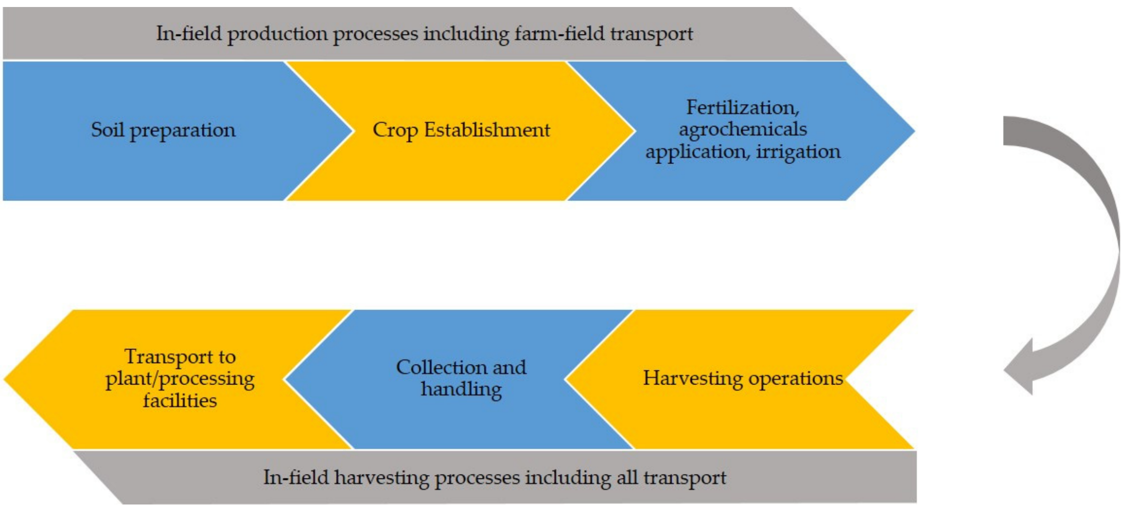

Figure 2. Processes included in this review's boundary.

3.2. Information Sources

There are a total of 52 studies included, which withdrawn from the electronic databases: Web Of Science, ScienceDirect, Wiley Online Library, and SpringerLink. The primary searches were implemented in the mid-end of January 2019. It is possible that any newly emerging publication after this date is not included. Nonetheless, the keywords, their combinations, and the searching strings are saved in order to make the whole process replicable for future use.

In the present review, no grey literature is included (i.e., any literature produced in electronic or print format that has not been controlled by any commercial publisher, for example, technical or research reports, doctoral dissertations, etc.).

4. Biomass-Type Classification Frameworks and Analysis

The existing literature regarding green, yellow, or woody biomass sources was classified in the following categories: (1) Literature focusing on supply-chain strategic planning, and (2) literature regarding operational planning for a series of operations (or the whole system) throughout the supply chain. In the term "supply-chain strategic planning", system productivity or life cycle analysis (LCA) (or energy consumption/balance assessment) of the biomass crop under study was considered. In a similar way, any financial/economics evaluation of a certain crop production/operational processes would be included under supply-chain strategic planning. However, these categories are not rigid and there is high possibility a particular work could be incorporated in both of them. A brief summary of the literature allocated to these categories according to the specific biomass type reported is presented below.

4.1. Green Biomass

4.1.1. Strategic Planning

Studies related to green biomass feedstock that include assessment of the system productivity or LCA analysis (including sub-categories such as energy consumption/balance, etc.) or financial evaluation are incorporated in this category. Apart from this, studies that include innovative design strategies throughout supply chain are also under consideration here.

An up-to-date geographical information system (GIS)-based approach by using a supply-chain simulation model is presented [7]. The objective of the presented approach was the determination of the optimal locations of beet crops that maximizes the profit of bioethanol production plants. Another study on allocation of energy crops to dispersed field locations is the one presented by [8], where a crop-to-field allocation tool targeting the maximum energy gain of the system was proposed. In that study, energy consumption is considered for all in-field operations and transportation in the routes between farm-field and field-plant. The optimization problem was modeled both as a linear and as binary programming. Another simulation approach focuses on spatial geographical allocation of *Panicum virgatum* crop fields, storage facilities, and biorefineries were presented [9]. The work was based on a two-phase modeling process under the scope of economical sustainability of the supply chain components. This two-phase simulation included the implementation of the agricultural land management alternative with numerical assessment criteria (ALMANAC) model for crop productivity simulation combined with the AnyLogic simulation model that is capable, among others, of finding the optimal locations for biomass storage facilities.

In [10], alternative supply chain configuration scenarios in *Miscanthus* harvesting and transport were compared, financially optimized, and assessed from a sustainability perspective for different annual demand in biomass, yield, and time of harvesting, among others. For the same energy crop, a computational tool was presented by [11], based on an in-depth analysis and energy requirements estimation of individual *Miscanthus* fields, including all the in-field operations and transportation. An economic approach based on the implementation of GIS was implemented to evaluate green biomass (*Miscanthus* and *Panicum virgatum*) SCM under different structures of the supply chain [12]. The scale of examination was downsized from county-level to field-level in order to more easily find the suitable individual areas for biomass production and, in this way, allowing microeconomic evaluation and modeling.

Miscanthus was also under the scope of study in terms of supply-chain strategic planning considering the production operations [13]. A simulation model called Simulateur mulTIdiscplinaire pour les Cultures Standard (STICS) was presented (as an improvement of an existing one) for the accurate prediction of the produced biomass in the long-term (up to 20 years from planting time) in various case studies. On top of this, the authors evaluated the nitrogen content in different cropping environments and in-field management practices. An approach based on soil maps, climatic data, and observed yields of *Miscanthus* fields was presented by [14] and in combination with GIS data concluded in the perspective of a decision support tool development for optimal supply-chain strategic planning. An optimization tool was also evaluated in the *Miscanthus* production supply chain and presented promising results as a decision support tool for farmers—in crop cultivation strategy development—and for policy makers—in monitoring and improvement of supporting practices [14].

A combined financial and energy requirements analysis was conducted by [15] for harvesting and transportation operations in *Arundo donax* production systems. Targeting the optimal strategic planning of supply chain, different operational alternatives were proposed.

Sugarcane is evaluated in [16] study, which focuses on sugarcane SCM and also on green harvesting residues management under different operational practices. The authors developed a simulation model to present the biomass flow through the whole supply chain (in-field and transport operations). Except for operational constraints, they also took into account weather and geographical constraints to identify possible bottlenecks in the supply chain and biomass availability, such as non-synchronized harvesting, handling, and transporting operations.

Triticale is a hybrid of wheat and rye not widely considered as a crop for bioenergy production. A study that focused on the assessment of triticale as a potential biorefinery feedstock is the one presented by [17]. They introduced improved harvesting methods that have a positive effect on costs reduction and availability secure of high-quality biomass in the long-run. A number of autochthonous perennial grasses, as potential crops for biomass production, were evaluated in terms of supply chain efficiency [18]. Authors conducted a four-year experiment to examine parameters such as energy efficiency, crop yield, and water-use efficiency.

Energy balance estimation comes to the center of interest for complex biomass production systems, as presented by [19]. More analytically, they presented an assessment process for the energy balance of multiple-crops and multiple-fields systems by implementing a web-based tool. Three different crops were evaluated as a case study, namely corn silo, wheat, and rapeseed. In [20], multiple-production systems were also evaluated by developing and implementing a comparative computational tool potentially applied to any set of given crops, given energy-related or production-related input, and according to any specific production practices. A study that refers to different bioenergy cropping systems is presented by [21]. They evaluated the productivity of selected systems by using experimental data that were further analyzed by a simulation tool to identify potential limitations of resource-use efficiency on biomass dry matter yield.

Carbon footprint assessment throughout the supply chain is included also in supply-chain strategic planning. An integrated assessment of commercial crops (such as *Maize*) with bioenergy crop production (such as switchgrass) can be an innovative way for biomass supply-chain strategic planning, as presented by [22]. Authors took into consideration the effect of SCM practices on cost, yield production, and system sustainability. A multiple-crop CO_2 annual emissions estimation regarding cultivation processes was conducted by [23]. In addition to this, they made a long-term (for a 30-year period) prediction of the CO_2 emissions for the selected crops in order to identify the most sustainable crop(s), from the environmental point of view, for bioethanol production. Environmental impact assessment of multiple perennial green biomass crops in marginal land was presented by [24], based on crop comparison under specific conditions and further development and improvement of the supply chain.

4.1.2. Operational Planning

A multiple-optimization strategy was followed considering the impacts of operational management on minimization of costs, maximum, yields, and sustainability of *Panicum virgatum* supply chain [22]. For this scope, authors modeled the integration of *Panicum virgatum* on a real corn production field and its effects on profitability, productivity, and environmental improvements of the system by using mainly the landscape environmental assessment framework (LEAF) tool (Version 2.0, United States).

Arundo donax is also the target energy crop in study [25], where authors provided an agronomical assessment testing on the crop structure and regrowth potential as they are affected by the harvesting time. They further compared different harvesting alternatives and evaluated the biomass quality based on the harvesting parameters, such as harvesting time and harvesting frequency.

Sweet sorghum and sugar beet are two important energy crops for bioethanol production. In this light, many studies have focused on the SCM of these crops. The biomass yield of sweet sorghum and sugar beet was estimated in an experimental study in southern Italy [26]. In the same work, the energy performance under different in-field operational management scenarios was evaluated for these two crops. The effect of three levels of shade (low, medium, and high) on *Maize* production (such as growth and yield) that is cultivated for biogas production was evaluated in [27]. These levels of artificial shading were presented to affect the biogas-related parameters (such as leaf area index and energy availability for plant growth) and the final biogas and methane yield. In a *Miscanthus* production system, biomass production, costs, and supply-chain constraints are considered in a whole supply chain financial optimization strategy [10].

There is also reference considering specific aspects of supply-chain operational issues in green biomass crops. The optimized design of the in-field operations following optimal route planning (B-patterns) under the objective of minimizing energy cost was assessed in two green cropping biomass production systems (*Miscanthus* and *Panicum virgatum*) [28].

4.2. Yellow Biomass

4.2.1. Strategic Planning

The establishment of biogas plants in the optimal location is directly connected to crop residue-related parameters (such as quantity, accessibility, weather conditions, etc.). Regarding the strategic planning of yellow biomass supply chain, the models multiple linear regression and artificial neural networks (ANNs) were implemented for the estimation of available crop residues (specifically, corn stover and wheat straw) in multiple sites [29]. In the same work, potential suitable locations for bioenergy plants are identified by this approach, and subsequently, the optimal plant location is suggested together with the biomass delivered cost. For the same crop residues, authors in [30] calculated the potential sustainable yellow biomass quantities while maintaining soil productivity and health. They focused on large-scale bioenergy applications and proposed the establishment of sustainable removal rates of residues and supply chain cost for various regions.

A simulation-based model that considers multiple-locations assessment and selects the optimal location for bioethanol plants based on parameters such as wheat biomass density, supply chain network, etc., was presented by [31]. The focus was on the financial analysis and environmental impact assessment.

Regarding crop residues from corn production (stover), different biomass handling and transportation scenarios were evaluated under an LCA analysis in [32]. The selected scenarios included combinations of biomass handling (in bale form or pelletized form) and either storage in an intermediate depot or by directly transportation from field to the biorefinery.

Cotton stalks represent another type of crop residue biomass. In [33] an integrated GIS and an ANN high spatial resolution model was developed to assess available cotton stalks harvesting and transportation. In addition, by GIS analysis the suitable biorefinery locations were selected under the criterion of the minimum total transport distance and the delivered cost. Finally, the estimation of spatial and temporal variations of potential cotton stalks in the United States was presented by [34], including also an assessment of different SCM practices for cotton stalks under an engineering economics approach.

A GIS-based model taking into account various features connected to a geographic region in order to determine the location of biomass-processing facilities considering also uncertainty factors [35]. These factors are connected to the availability of crop residues, other environmental, financial, weather, or even social constraints. In this study, residues coming from various crops are used, such as corn, sorghum, sugarcane, wheat, barley, agave, rice, and pecan nut. The development of a spatial decision tool is also the main objective in [36], with the aim of advancing this research field. The developed tool is useful at the strategy development level where the decision making is conducted. The optimal alternative solutions or combination of them were determined by identifying the best regions for the establishment of biomass plants, according to the crop residue availability, by including also factors such as geographical features, accessibility of the crop residues points, and the complexity and structure of the logistics network. Multiple types of crop residue biomass were also under consideration in [37]. Authors presented a location-route collaborative optimization model that they used to design the multiple residues collection network and corresponding routes. The yellow biomass considered was stalk, leaves, etc., from crops such as cereals and beans, tobacco stalks and leaves, stalk from beet, sugarcane, among others. The sites were depicted by nodes and thus the node capacity of the network and the logistics cost were the basis for the main modeling structure. On top of that, they proposed and built a mathematical algorithm to solve the location-routing problem under specific constraints.

4.2.2. Operational Planning

Fruit orchards, vineyards, and olive trees are of high biomass interest given the produced residues in the field. On this, [38] presented an integrated framework for the development of a decision support tool for logistics operations of fruit trees, vineyards, and olive tree pruning and branches. In this work, the necessity of a "smart logistics system" is presented. Additionally, the components of this system under certain technical and other requirements and constraints were defined together with the determination of the information to be managed by the system. The olive tree-pruning biomass supply chain was accurately estimated and optimized on supply-chain development and modeling frameworks [39].

Innovative techniques that include quantification of pruning biomass residues coming from individual olive trees and based on LiDAR (light detection and ranging) data processing methods were used by [39]. Their work is of high value for supply-chain operational planning given that they focused on the accurate estimation of the biomass volume and distribution and other aspects such as supply-chain modeling and development.

4.3. Woody Biomass

4.3.1. Strategic Planning

SCM is quite significant also for woody biomass considering strategic planning. Authors in [40] analyzed the viability of eucalyptus supply chain and further evaluated the optimal location of a power plant to be fed by wood. Their analysis was based on GIS databases to calculate available biomass under certain restrictions. Even though this work is one among many that target the optimal bioenergy plant localization, their methodology includes calculation of optimized costs and CO_2 emissions throughout the supply chain considering local and regional data. Authors in [41] developed a discrete event simulation model for techno-economic assessment of harvesting, handling, and transport operations for the supply of short-rotation coppice willow (SRCW) to energy conversion plants. Their main objective was to suggest cost-effective supply chain solutions in order to deliver all-year-round SRCW to the biomass plant.

Poplar short-rotation coppice (SRC) belongs also to woody species under consideration for biomass production. In the work presented in [42], the most important environmental impacts of wood chips production from poplar SRC on marginal land were provided in detail, and a comparison was made between common SCM practices and alternative SCM practices in terms of modified harvesting and handling systems, irrigation, and fertilization.

Eucalyptus is included in the woody biomass SCM category and is considered one of the most commercial woody crops cultivated for bioenergy production. In [43], the economic viability of various operational practices regarding whole eucalyptus tree trunk production was analyzed under varying production and economical parameters. To analyze risk management a Monte Carlo analysis was run. Stochastic models also included different planting densities and arrangements in order to provide a framework for assessment of financial risk applied in decision analysis for bioenergy crop investments.

Willow was under consideration in study [44], where part of the supply chain was modeled and evaluated (harvesting, collecting, and transportation). Authors run the integrated biomass supply analysis and logistics (IBSAL) simulation model (Oak Ridge National Laboratory, Oak Ridge, TN, United States) in a significant number of SR willow fields and evaluated the effect of the major input factors (i.e., parcel size, field shape, crop yield, field-to-plant distance, and type of collection machinery) in the performance of the system.

An innovative mobile application for application in mostly woody biomass supply-chain strategic planning was suggested by [45]. The objective was to create a useful tool for the farmers in order to be able to evaluate the energy potential of tree pruning in their own orchards, share the information regarding the specific region that the orchard belongs, and match this data with the availability for heating energy in agro-industrial or other buildings.

4.3.2. Operational Planning

In [40], optimization of supply chain was pointed out, targeting the optimal location of wood-fired plants under specific constraints. SRC willow, as it has been presented above in [41], is under the scope of supply-chain operational planning (regarding harvesting and handling operations) in the supply chain from field to plant. Additionally, the impact of the most significant input factors was evaluated regarding the total willow supply chain performance [44].

Poplar tree production was also evaluated on part of the supply chain related to cultivation and harvesting operations [46]. The main objective was to point out the environmental impact of poplar trees cultivated in various soil nutrient levels and suggest the optimal strategy. Similarly, in poplar SRC, optimization of cultivation and transportation practices through a financial and environmental analysis was presented by [47].

Regarding woodchip transportation on a short supply chain (up to 70 km distance), an analysis of the energy input and the carbon dioxide emissions was conducted by using two types of transportation means (i.e., agricultural tractors or industrial trucks) and carrying out a thorough analysis under parameters related to road design (such as, traffic lights, intersections, etc.), traffic conditions, and road surface conditions (such as rain, fog, ice) [48].

4.4. Multiple Biomass

4.4.1. Strategic Planning

Several studies include combination of green and yellow biomass supply-chain strategical and operational planning. A work that combines green and yellow biomass SCM based on agro-ecosystem models was presented by [49]. The main objective of the work was the supply chain assessment and design (including crop production and transportation) under the demand of a bioethanol plant with feedstock from three types of crops grown for different purposes, namely: crop residues; annual crops; and perennial crops (i.e., wheat straw, triticale, sorghum, and *Miscanthus*). The developed model focused on productivity measures and the environmental impact of the supply chain. Among others, the scope of the model was the minimization of the balance between food and feed crops. Under the scope of farmers' profit maximization and of environmental sustainability, a landscape approach for the assessment of multiple various-sized subfields was carried out in [50]. They evaluated opportunities coming from yellow biomass collection and transportation together with green biomass potential development on low-perspective fields that normally make no profit.

Supply-chain strategic planning is underlined by energy balance estimation of in-field and transportation operations research studies regarding green and woody biomass types, such as the ones presented by [19] and [51].

A comprehensive model that can be applied for strategic planning of green, yellow, and woody biomass supply chain was presented in [52], where authors developed a mixed-integer linear programming model that targeted the minimization of the establishment cost of the integrated supply chain under specific constraints (e.g., biomass availability, capacity of technology, etc.). Authors divided the supply chain in two parts: The biomass supply chain that referred to the part from field to biorefinery, and the liquid fuel supply chain that referred to flows of ethanol and blended fuels from biorefinery to gas station. The focus of the developed model was on supply-chain-related solutions and biomass-related solutions that may contribute to a more financially viable supply chain.

Finally, a CyberGIS platform (CyberGIS Gateway, Illinois, United States) was developed by [53] as a decision support tool for biomass supply-chain management and analysis. More specifically, authors described, in their model, how to integrate optimization within the CyberGIS platform in order to solve complex spatial decision-making problems throughout the supply chain.

4.4.2. Operational Planning

Another study combined green and yellow biomass assessment [54]. Authors evaluated both production and transportation operations of corn (stover) and *Panicum virgatum* under two different baling systems, and, in a second step, they compared the corresponding supply chains financially, in terms of energy cost, and in terms of GHG emissions.

Operational management practices were assessed within three different designed supply chains of green biomass in terms of operational times and costs [55]. In particular, three different approaches where simulated and the effect of yield uncertainty and machinery productivity were evaluated based on a sensitivity analysis approach. Authors in [56] proposed a simulation approach for the optimal biomass bales location. Various bale aggregation methods were simulated and evaluated in terms of the required in-field transport operations for different methods. Similarly, on [57] authors simulated the in-field layout of biomass bales, providing the desired bale stacks layout under various different parameters (such as field area and shape, yield, bale mass, etc.) for increasing the efficiency of biomass handling and transportation operations.

Scheduling of handling and transport operations is considered crucial in any biomass supply-chain strategic planning. In this light, a tool was developed for scheduling of field machinery used in these operations in geographically-dispersed fields under specific constraints [58]. In that work, authors presented an algorithm that creates individual working schedules for multiple machines that carry out more than on consecutive operations at multiple fields, taking into account the given readiness in each specific field on the specific timing. They used a basic Tabu Search method and a modified one that produces optimized work planning.

5. Methodological Approach-Based Classification Framework

The research studies, which were already classified above in two levels, can be further classified according to the methodological approach followed in each cited work. In this light, the four categories of included studies (i.e., green, yellow, woody, and multiple-type biomass) were kept the same as in the previous classification framework. The studies related to green-type biomass are summarized and presented in Table 1.

Table 1. Green-type biomass cited studies classified by crop and approach.

Cited Work	Crop(s)	Methods/Models	Criterion	Data Sets	Time Frame
[7]	Energy beet	Simulation	Maximization of profit of potential ethanol plants	Yields, production, and transportation costs, agricultural opportunity costs, ethanol production, and ethanol prices	N/A
[27]	*Maize*	Experimental approach evaluated by statistical analysis	Evaluation of biomass and biogas yields	Plant growth, yields, biogas, and methane yields	3 years
[17]	Triticale	Techno-economic computational model	Reduction of feedstock procurement operational costs, secured feedstock availability, and increased high-quality biomass supply	Triticale production data and biomass yields, commercial machinery data	1 year
[9]	*Panicum virgatum*	Two-phase simulation location-allocation modeling approach	Minimization of operational cost of the supply chain	Field, weather, and soil data sets, cost, demand, and price data and actual transport-related data	1 month
[18]	Wild perennial crops	Experimental approach together with statistical analysis	Biomass yields, biomass quality, and water-use efficiency	Meteorological data, soil water data, crop-related data	4 years
[10]	*Miscanthus*	Four-step assessment framework (i.e., design, optimize, assess, and compare biomass supply chains)	Economic optimization	Field and crop data, operational data, financial and energy-related data	1 year
[23]	Sugarcane, sugar beet, corn, rice and cassava	Experimental-based approach together with carbon flux assessment model	CO_2 emissions	Crop-related data, soil data, carbon emissions data, etc.	1 year
[12]	*Miscanthus* and *Panicum virgatum*	An economic, biophysical, and GIS modelling approach	Supply-chain structure and prices	Yields, climate data, field-related data, etc.	15 years
[11]	*Miscanthus*	Simulation	Energy requirements assessment	Operational data, machinery data, energy input, crop data, etc.	10 years
[15]	*Arundo donax*	A computational approach on economics and energy consumption based mainly on experimental data	Cost-effectiveness and environmental sustainability	Financial data, operating data, machinery and transport data, etc.	Annual
[14]	*Miscanthus*	A multiple regression modeling approach together with remote-sensing modeling approaches and experimental data	On-farm productivity	Soil water, climate data, georeferenced data, crop growth data, field and crop data, etc.	≥ 5 years

Table 1. *Cont.*

Cited Work	Crop(s)	Methods/Models	Criterion	Data Sets	Time Frame
[26]	Sugar beet and sweet sorghum	Simulation and experimental-based approach	Energy performance	Field and crop data, meteorological data, machinery data, operational data, etc.	3 years
[25]	*Arundo donax*	Experimental approach and statistical linear model	Biomass yield and quality	Climate data, productivity, and biometrical data, soil, site and crop data, etc.	2 years
[22]	*Panicum virgatum*	Multi-criteria decision analysis technique	Reduction of economic losses and maximization of environmental performance	Soil and crop data, profitability data, climate data, operational data, etc.	1 year
[8]	*Miscanthus*, *Panicum virgatum*, and *Arundo donax*	Binary and linear programming simulation models	Optimal energy performance	Crop and fields data, machinery data, material data, energy coefficients, etc.	10 years
[13]	*Miscanthus*	Simulation	Yield and N content	Crop and field features, soil, climate, agricultural practices, etc.	4–20 years
[16]	Sugarcane	Simulation	Cost, energy, and emissions	GIS data, weather data, farm data, operational data, etc.	Annual
[19]	Corn silo, wheat, and rapeseed	Web-based simulation tool	Energy balance	Fields and crop data, machinery and operational data, production means, etc.	N/A
[24]	*Miscanthus*, *Panicum virgatum*, *Arundo donax*, and cardoon	Simulation	Environmental impact	crop data, operational, production means, weather data, etc.	15 years
[20]	*Miscanthus*, *Panicum virgatum* and *Arundo donax*	Computational simulation tool	Energy cost	Fields and crops data, machinery and operational data, transportation, production means, and materials, etc.	10 years
[28]	*Miscanthus* and *Panicum virgatum*	Simulation	Energy consumption savings	Field and crop data, machinery data, operational data (turning radii, operating width), energy input, etc.	Annual

Another significant share of the potential biomass sources for bioenergy production regards yellow-type biomass. The studies that include agricultural residues SCM—only those that come from crop production and not any agricultural residue—are presented in brief in Table 2. These studies include various methods such as simulation and experimental methods, but also real-time artificial intelligence methods that are connected to machine learning technologies; technologies that have lately emerged in the agricultural sector [59].

Similarly, with the previous two literature categories, Table 3 regards studies correlated to woody biomass SCM approaches that come from woody crops but not common forest species. Moreover, in Table 4 the studies that refer to SCM of more than one different type of biomass feedstock are listed.

6. Discussion and Conclusions

In this review, 52 research studies were included in total, published in 24 different journals (Figure 3). "Biomass and Bioenergy" represent the most referenced journal in the current review followed by "BioEnergy Research" and "Journal of Cleaner Production".

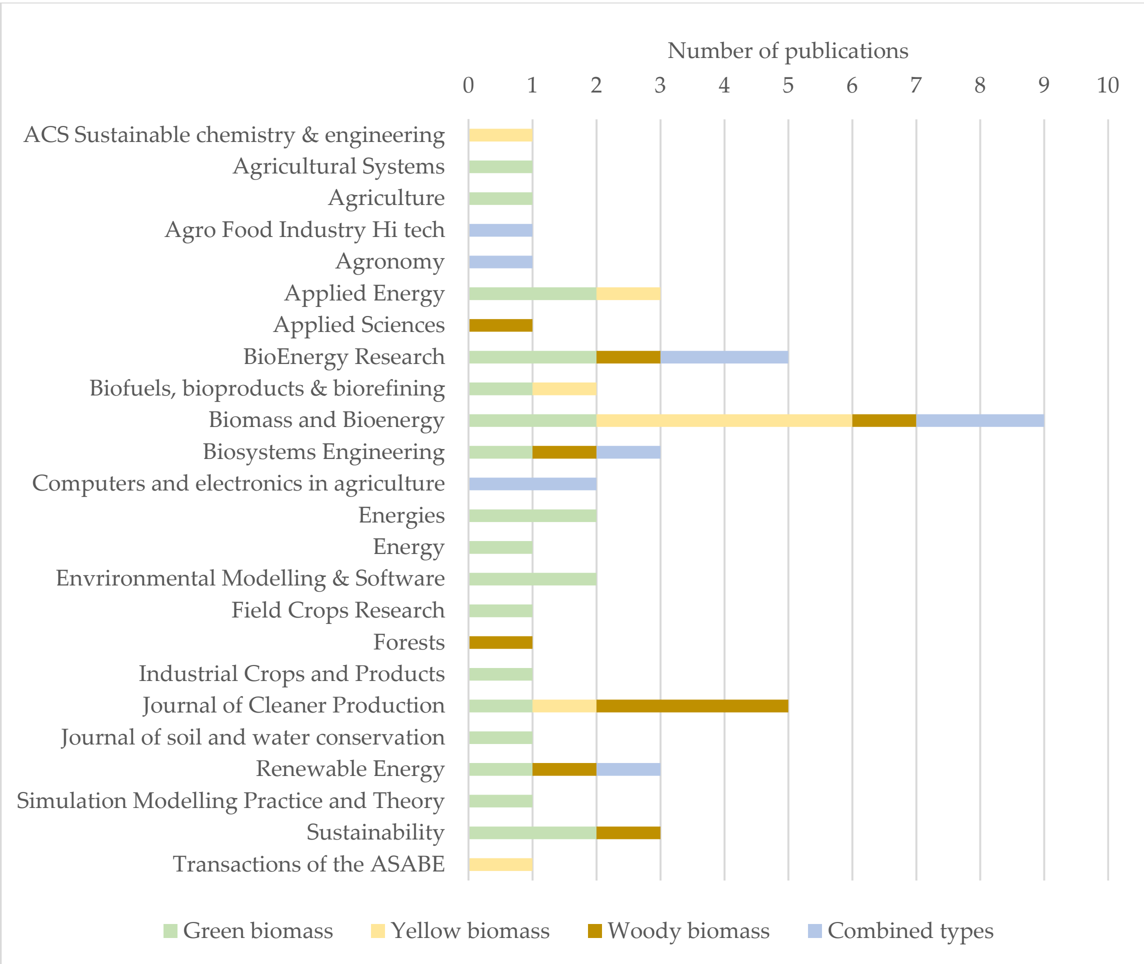

Figure 3. Number of papers extracted by each journal.

Table 2. Yellow-type biomass cited studies classified by crop residue and approach.

Cited Work	Type of Crop Residue(s)	Methods/Models	Criterion	Data Sets	Time Frame
[29]	Corn stover and wheat straw	Multiple linear regression and artificial neural networks (ANN) model	Crop residues availability, identification of optimal plant locations, and cost minimization	Crop yield, soil-related data, operational and financial data	Annual
[32]	Corn stover	Open LCA software-based modeling approach and Monte Carlo simulation	Environmental impact of supply chain versus densification and pelletization	Field trials and crop data, operational data, emission, and biomass related data	Annual
[31]	Wheat straw	Simulation-based approach	Minimum ethanol plant capital and operating costs in parallel with maximum profitability	Financial and environmental data, operating data	20 years
[33]	Cotton stalks	An integrated GIS and ANN prediction modeling approach and linear programming models	Yellow biomass availability, optimal plant location with the minimum supply-chain cost	Crop data, transport network data, weather data, geospatial data	5 years
[30]	Corn stover and wheat straw	Analytical modeling approach and simulation	Minimization of costs and environmental impact and maximization of energy efficiency	residual potential, machinery data, transport data, fields data, etc.	N/A
[34]	Cotton stalks	Analytical approach and simulation	Minimization of total delivered cost and energy input	Crop and field data, machinery data, operational data, etc.	Annual
[35]	Corn stover, sugarcane bagasse, sorghum straw, agave residue, wheat straw, rice straw, barley residue, and pecan nut shell	Geospatial optimization modeling approach	Optimal biomass processing location under uncertainty parameters	Spatial data, residual data, climatic data, terrain, and crop data	5 years
[36]	Cocoa crop residues	An integrated GIS-based fuzzy analytic hierarchy process (AHP) programming approach	Biomass availability, transportation, and slope feasibility	Crop yields, geospatial and land data, road data, accessibility, natural hazard, etc.	Annual
[39]	Olive trees pruning residues	Experimental approach based on LiDAR (light detection and ranging) technique	Quantification of olive trees pruning	Dendrometric data, field data, LiDAR data, etc.	N/A

Table 3. Woody-type biomass cited studies classified by crop and approach.

Cited Work	Crop(s)	Methods/Models	Criterion	Data Sets	Time Frame
[46]	Poplar	Simulation and experimental-based approach	GHG emissions	Field and crop data, operational and machinery data, emissions inputs, etc.	20 years
[47]	Poplar SRC	Modeling approach by using SimaPro tool and by using experimental data	Environmental and energy performance, economic viability	Yield and crop data, operational data, machinery data, energy and emissions input, economics, etc.	12 years
[43]	Eucalyptus	Financial analysis of different experimental silvicultural practices evaluated by Monte Carlo simulation	Investment analysis criteria such as net present value, internal rate of return, and profitability	Experimental, various economical and statistics-related data	3 years
[44]	Willow	IBSAL simulation model	Highest performance of the integrated system based on parcel size, field shape, crop yield, storage location, and collection equipment	Field trials data and commercial machinery data	5 years
[48]	N/A	Experimental-based approach combined with linear programming modeling	Energy requirements and CO_2 emissions	Vehicles-machinery data, road/traffic data, operational data	2 months
[40]	Eucalyptus	A computational approach based on WISDOM database and by using the network analyst tool	Minimization of costs and GHG emissions	Machine productivity data, operational data, yields, emissions data, road network data,	Annual
[41]	SRC Willow	Discrete event simulation modeling	Cost effectiveness	Weather data, transport data, yields, geographical conditions, soil water content, storage-related data, machinery data	Annual
[42]	Poplar SRC	Experimental approach based on growth model MoBiLE-PSIM and Umberto Software	Environmental impacts	Operating data, machinery data, field and crop data, growth data, etc.	20 years
[45]	Fruit trees	Mobile application development and performance approach	Biomass availability matching with heating energy requirements of agro-industrial buildings	Yields, energy requirements, climatic data, etc.	N/A
[38]	Fruit tree, vineyards, and olive grove prunings and branches from up-rooted trees	Smart Logistics System Prototype development and performance	Optimization of supply-chain performance	Biomass-related data, spatial data, weather data, etc.	N/A

Table 4. Multiple-type biomass cited studies classified by crop and approach.

Cited Work	Crop(s)/Residues	Methods/Models	Criterion	Data Sets	Time Frame
[37]	Woody and agricultural residues	Simulation and genetic algorithm development	Cost of transportation routes	Spatial data, yields, transportation and operating data, storage, etc.	N/A
[56]	N/A	Simulation and regression models	Logistics efficiency	Spatial data, crop and field data, transportation, etc.	N/A
[57]	N/A	Simulation	Logistics distances	Field and crop data, operational data, spatial data, transportation, etc.	N/A
[58]	N/A	Scheduling algorithm development	Field readiness	Crop and field data, operational data, transportation, etc.	N/A
[55]	N/A	Simulation	Task times and cost performance	Field data, transportation, operational data, machinery data, economics, etc.	N/A
[51]	Potential for up to 30 listed biomass crops	Web tool development	Yield and cost	Production data, fields and crops data, economics data, machinery, and operational data, etc.	N/A
[21]	Combination of various crops and crop residues	Experimental and simulation modeling	Productivity and resource-use efficiency	Data related to crop growth, field, weather and soil water	2 years
[52]	Various crops and crop residues	Mixed-integer linear programming optimization model	Minimization of the entire cost of the integrated bioethanol supply chain	Regional statistical data, crop-related data, operational cost data	N/A
[49]	Triticale, sorghum, and *Miscanthus*	Simulation-based approach	Optimal feedstock supply-chain strategic planning based on agro-ecosystem modeling	Data related to weather, crop management, soil, emissions, operations, etc.	20 years
[50]	Residues and energy crops	Simulation-based approach	Farmer's profitability and environmental sustainability	Crop rotations data, field-related data, soil data, weather data, operational and financial data	5 years
[53]	N/A	CyberGIS-enabled decision support platform development	Supply chain optimization	Spatial, agricultural (yields, production costs), and engineering/technology related data (such as transportation and operating data, etc.)	N/A
[54]	Corn stover and *Panicum virgatum*	Simulation	Minimization of cost and energy consumption	Machinery data, operational data, financial and energy data, yields, etc.	10 years

Generally, the use of final biomass product may vary, either for heating or electricity production closer to its primary natural form (i.e., pure biomass), either by converting biomass to biofuels (such as bioethanol, biodiesel, or biogas) through biorefining processes. Here, three main categories (namely biomass, biogas, bioethanol) as types of final product were pointed out in the included literature and presented in Figure 4, classified further to each different type of biomass. According to the literature, in the case of multiple types of biomass sources, the final product mostly leads to direct biomass use and less to bioethanol production. In parallel, literature shows that green and yellow biomass types may be equally used for biogas production. Regarding the bioethanol-related works, all types of biomass are referenced except woody type. This is also representative of the existing situation in bioethanol and biogas production industries.

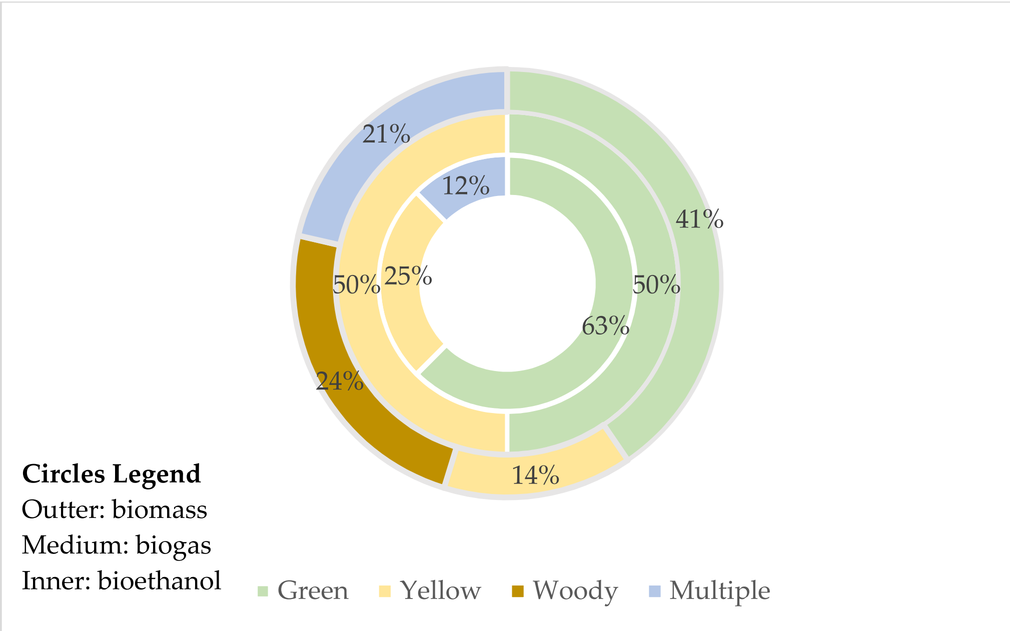

Figure 4. Biomass type in relation to the final product.

The reviewed literature was assessed under the methodological approach defined above and the results were presented in Tables 1–4 for each biomass-type. An aggregated representation of this categorization is presented in Figure 5. In general, various types of simulation approaches were used in almost 43% of the total studies of this review, while 26% used experimental methodological approaches and 31% used other types of approaches, such as online tools, web applications, etc.

As previously mentioned, the parts of the supply chain that were included in this review correspond to the stages from in-field production processes up to transportation to the biomass processing facilities, including any intermediate steps of the chain. However, the steps of the supply chain included in each conducted study varied. On this, eleven different combinations of supply chain steps were found in total in all biomass types. The number of works allocated to each one of these categories is presented in Figure 6. There is a significant amount of studies—19% of total—that correspond to in-field production and biomass transport stages, while 17% of the studies are targeted to in-field processes.

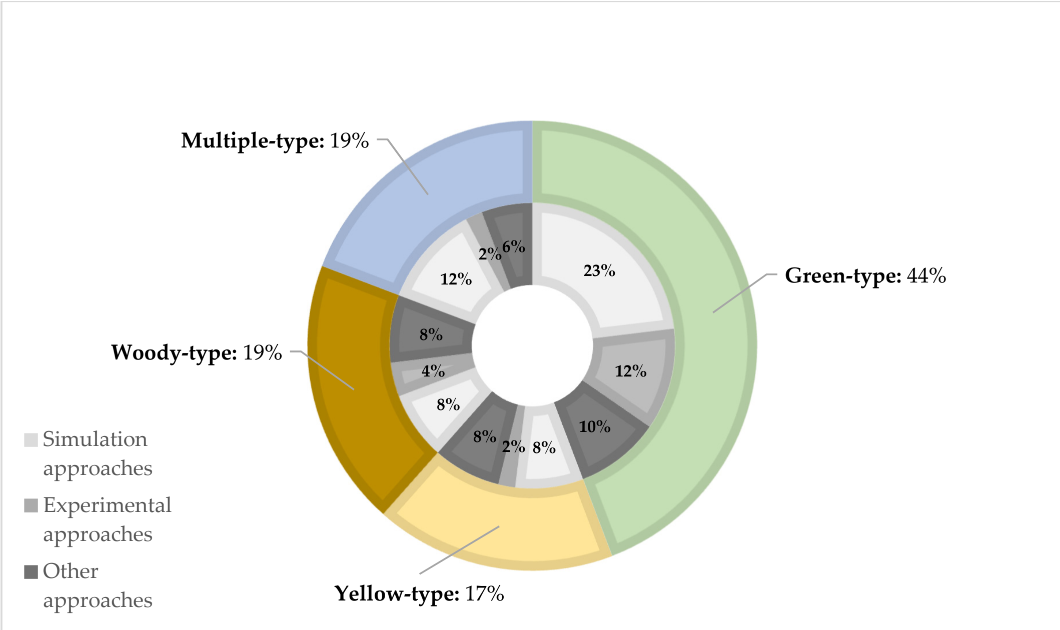

Figure 5. Biomass type and methodological approaches correlation.

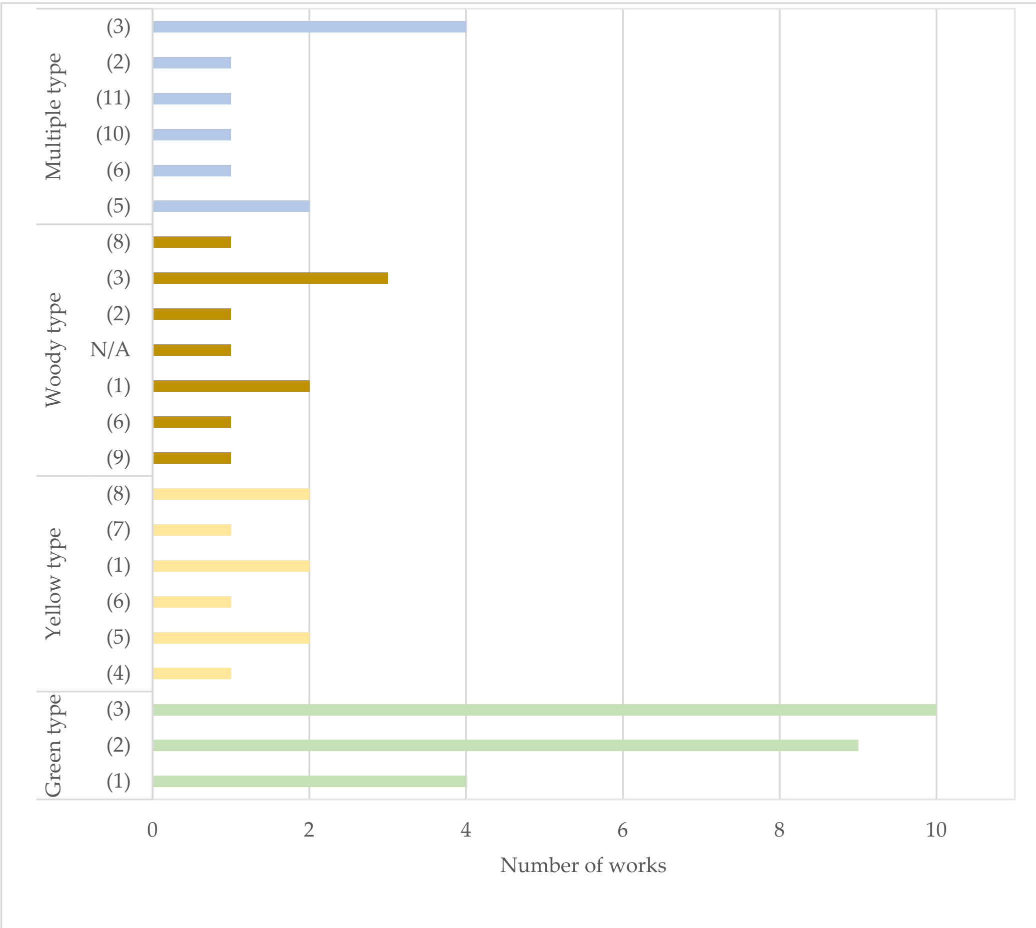

Figure 6. Number of works allocated to various parts of supply chain: (**1**) Harvest and transport; (**2**) production; (**3**) production and transport; (**4**) collection and quantification; (**5**) collection and transport; (**6**) handling and transport; (**7**) harvesting, collection, transport, and handling; (**8**) transport; (**9**) harvesting, collection, and transportation; (**10**) harvesting and handling; (**11**) harvesting, handling, and transport.

Among the articles, three supply chain categories are related to energy crops biomass production and six categories are connected to crop residues biomass supply-chain management. On top of this, there are seven categories related to woody energy crops biomass supply chain and six categories are presented to connect with studies that take into account more than one type of biomass (such as combined green- and yellow-type).

Overall, 52% of the referenced publications are related to strategic planning of supply chain, 29% of the works are related to operational planning, while 19% of the works present combined methods (targeting strategic and operational planning of supply chain). Green biomass-related literature includes approaches related to strategic planning (12 works), operational planning (five publications), while there are four works that refer to both strategic and operational planning tasks of supply chain. Regarding yellow biomass literature, five and one approaches are, respectively, targeted to strategic and operational planning, while three works include both strategical and operational planning Similarly, for woody biomass literature, three works are related to strategic planning, four are related to operational planning, and three are related to approaches that combine strategic and operational planning of biomass supply chain. Finally, in literature that includes multiple biomass types, strategic planning of supply chain is targeted seven times, five works refer to operational planning, and three works are related to a combination of strategic and operational planning approaches.

Regarding the methodology-based framework, as it was presented in Figure 5, simulation techniques are the mostly used methodological tool in green-type biomass and multiple-type biomass systems. In yellow and woody type biomass, experimental approaches and other methods (such as analytical models, etc.) are the main methods.

Combining simulation methodological approaches to experiment-based methods in any kind of biomass type may result in the real evolution of these systems under the scope of optimal SCM. Moreover, in the future, methodological tools and other types of approaches are expected to contribute to this evolution by developing innovative real-time tools that would be useful, especially in solving problems in complex biomass systems. There is already a trend in this direction but this is quite dynamic and can be widely expanded more in many levels, both for the needs of the mentioned crops and systems but also in other biomass systems. By this review, an integration of different approaches is suggested for further evolution in currently-used methodology under the scope of production levels increase, sustainability enhancement of the systems at hand, and for ensuring bio-based product quality.

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