Chapter

Logistics Chain and Cost Assessment of Pruning-to-Energy Value Chains: Application of Life Cycle Cost Analysis Approach

Techane Bosona and Girma Gebresenbet

Abstract

Biomass from agricultural residue has significant potential as renewable energy resource. Therefore, cost-efficient processing and supply of agricultural residues are important to strategically plan and utilize this energy resource. This chapter describes the agricultural pruning to energy (PtE) value chains and presents the life cycle cost analysis (LCCA)-based cost assessment results, focusing on almond and peach tree pruning data obtained from Spain during 2015–2016. Along the main life cycle stages of PtE system, costs of harvesting, off-farm storage, transport, biomass loss, and management of biomass supply chain were considered. In terms of functional unit cost, the life cycle cost (LCC) was calculated to be about 126 €/t for almond PtE and 115 €/t for peach PtE value chain. In both cases, the harvesting stage was found to be cost at hot stage followed by the storage stage. The cost at harvesting stage was about 83% (of 126 €/t) and 82% (of 115 €/t) in the case of almond and peach cases, respectively. Similarly, the share of operational cost was about 74% and 76% for almond and peach cases, respectively. Therefore, more efforts should be made to improve the performance of logistics operations and management of such PtE initiatives.

Keywords: pruning-to-energy, life cycle cost analysis, almond tree pruning, peach tree pruning

1. Introduction

Reducing the use of fossil fuels and increasing renewable energy use contribute to sustainable energy use. In this regard, biomass from pruning residue could contribute a lot as an energy resource [1]. Due to some restrictions on nonrenewable energy sources such as fossil fuels and nuclear fuels, the use of renewable energy is expected to expand. Bioenergy is one of such renewable energy sources, and it is derived from biomass such as forests, municipal solid waste, and agricultural residues. Bioenergy could provide heating and cooling energy, electricity, and transport fuel [2]. About 60% of renewable energy sources in EU is bioenergy. However, there are challenges in production and supply of bioenergy in relation to: cost and efficiency of technologies; development of effective bioenergy supply chain from feedstock production to conversion into heat, electricity, and transport fuels; and how to integrate the bioenergy in the overall energy system [3].

Pruning is an important management practice for almond and peach trees [4, 5]. Globally, the land under almond tree cultivation in 2016 was estimated to be more than 1.8 million hectares while in Mediterranean areas, almond-tree pruning is one of largely available agricultural wastes as a fuel [5]. For example, Spain has devoted the largest area for almond tree cultivation and annually produces about 7.3×10^8 kg of almond tree pruning.

Even though agricultural pruning has a significant potential, it is not being utilized much for energy production because of several constraints such as cost and lack of technologies. Biomass-based energy production systems such as pruning-to-energy (PtE) initiatives should be designed well in order to reduce the financial and environmental cost [6]. Therefore, cost-efficient biomass supply is very important to strategically plan and implement more sustainable energy production from biomass including agricultural residues [7]. In such cases, cost models could include costs of harvesting, processing, transportation of biomass, procurement and supply chain management of biomass product, and the installation and management cost of power plants. In order to establish more optimized system, different methods such as location analysis (e.g., determining best location of biomass storage, power plant), transport route analysis, and integrated management systems could be applied [7–9].

This chapter presents part of the study that investigated the costs of fruit tree PtE value chains focusing on almond and peach tree pruning. The main objective of the cost assessment was to assess costs at different life cycle stages along PtE value using Life Cycle Cost Analysis (LCCA) approach. This enables to facilitate sustainable utilization of agricultural pruning as a source of renewable energy. It also facilitates the decision-making regarding PtE initiation in Europe and enables entrepreneurs to identify the type of logistics and process chains of lower investments.

2. Pruning-to-energy value chain and logistics configurations

The core processes in the PtE value chains include pruning, harvesting (collecting), processing, storage, transport, and energy production (see **Figure 1**). The main actors are farmers, harvesters (processors), traders, transporters, end users (owners of power plants), and administrator of the entire pruning supply chain. Different actors have different activities in the PtE value chain as indicated in **Figure 1**.

In the supply of pruning biomass, different logistics configuration types (LCT) could be designed depending on geographical conditions, biomass availability, and demand (see **Table 1** and **Figure 2**). For instance, if the pruning biomass quantity is limited, it could be used only for self-consumption. The storage facilities could be established on farm, off-farm, and at power plant. In most cases, off-farm

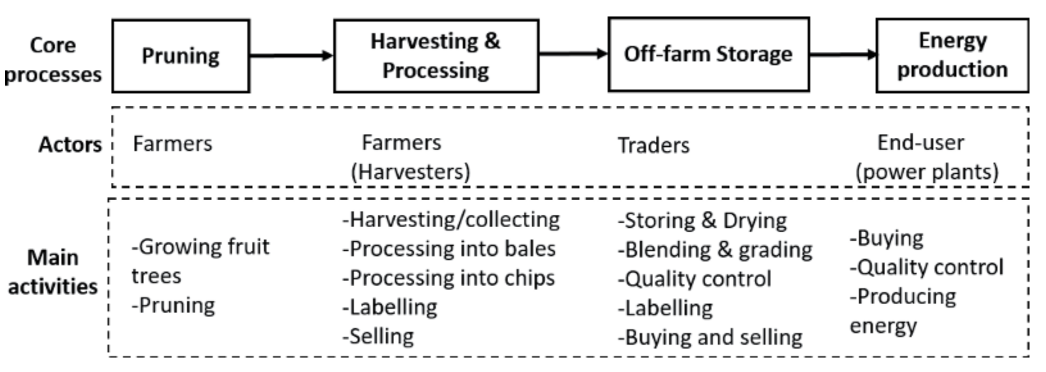

Figure 1.
Mapping of core processes, main actors, and activities along PtE value chains.

Type	Description
LCT1	Self-consumption (with or without storage), no significant transport
LCT2	On-farm storage, then direct delivery to final user
LCT3	Intermediate storage
LCT4	Direct delivery and storage at final user
LCT5	No-storage but direct delivery

Table 1.
Major logistics configuration types (LCT) pruning-to-energy value chain.

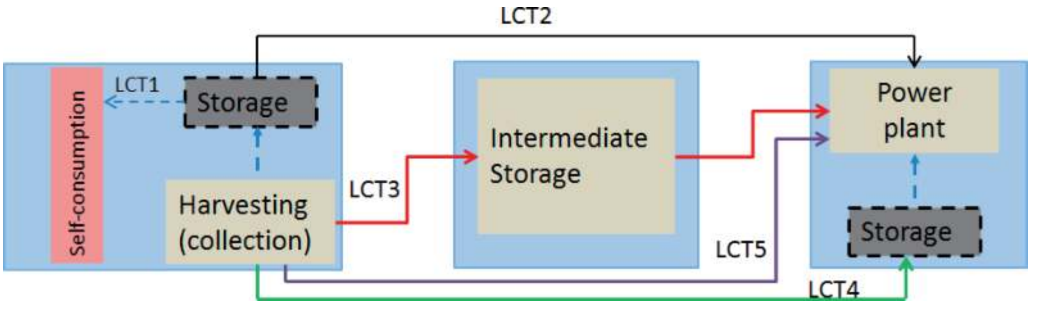

Figure 2.
Major logistics configuration types identified in the investigated pruning-to-energy (PtE) chains [10].

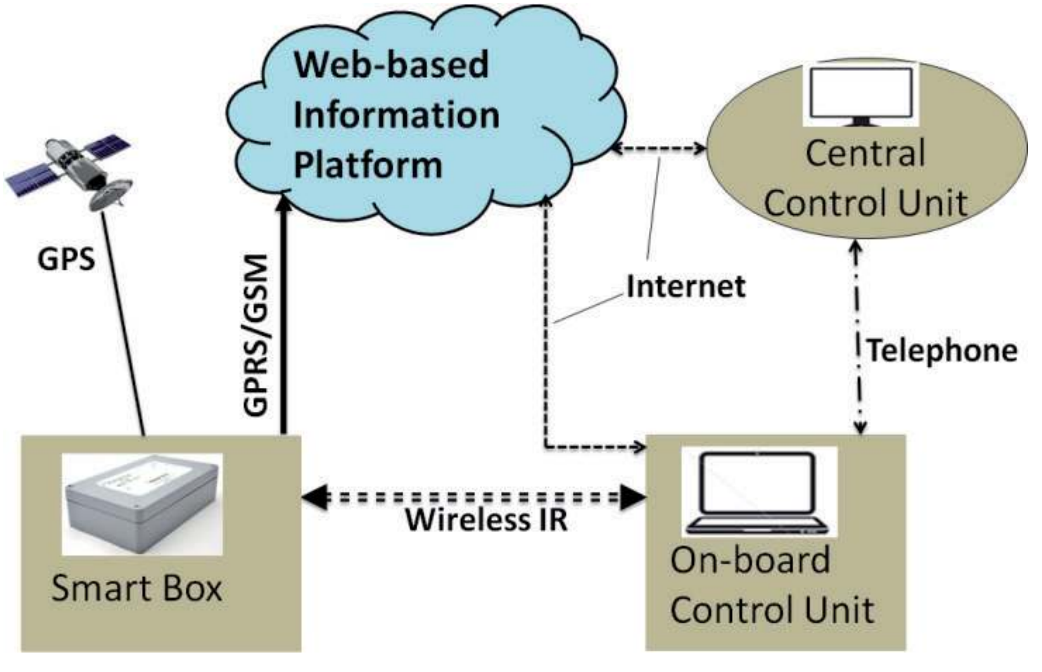

Figure 3.
Major components of smart system for coordinated management and monitoring of pruning biomass supply chain [11].

storage is used. Pruning biomass could be used as energy source at farm or could be sold to power plants either directly by farmers or through traders. Even though farmers, biomass traders, and end users are the major actors in these PtE initiatives, an independent management unit could be introduced as an actor, which could promote such PtE initiatives through application of smart systems for its

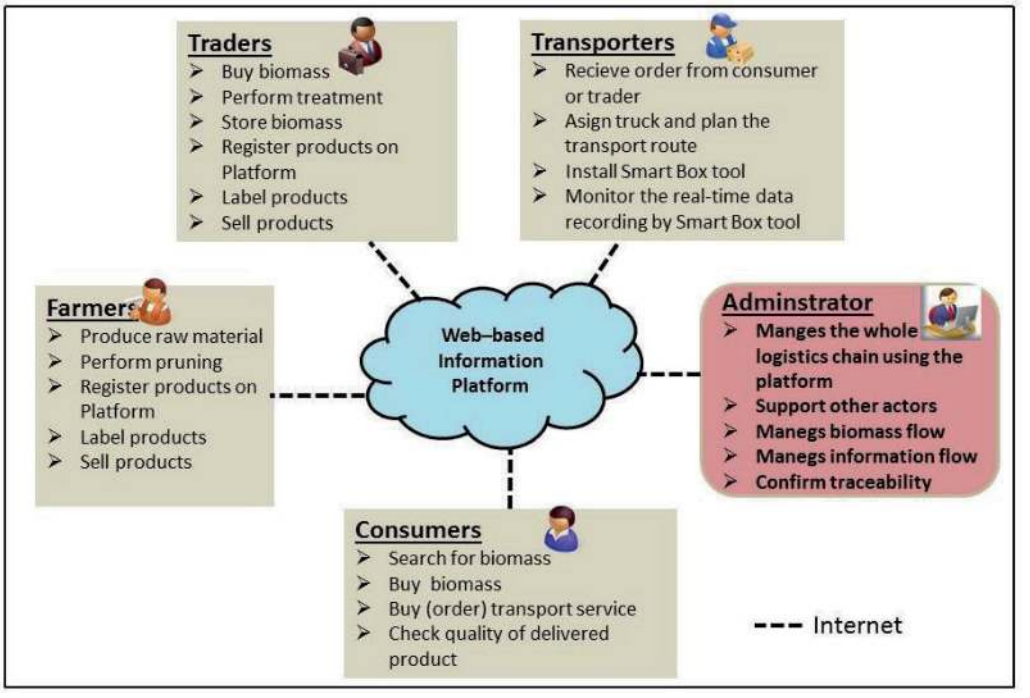

Figure 4.
Major activities of different users of the digital platform.

integrated management (see **Figures 3** and **4**). In relation to using smart system for coordinated management of the PtE initiatives, more actor-specific activities have been described in **Figure 4**.

3. Cost assessment of PtE value chain using LCCA

3.1 Life cycle cost analysis

Cost assessment is one of performance measurement areas, which include cost, asset assessment, productivity, customer service, and logistics quality [12]. In this chapter, life cycle cost analysis (LCCA) approach and its application to evaluate the economic performance of PtE initiative have been presented focusing on almond and peach tree pruning. By definition, life cycle thinking about a product considers the product from its inception to disposal [13]. Life cycle cost (LCC) is the total cost of owning and operating a product, facility, or a system over a period of time or its entire life span depending on the system boundary defined within the scope of the planed study [14].

Although LCCA was a tool originally developed by US Department of Defense, it is now applied in many industrial sectors [13]. It enables to make important decision in design, development, and implementation of projects or products with clear identification of cost distribution over the useful life span. To determine LCC value of a product or system, a bottom-up approach (e.g., engineering technique) and/or top-down approach (e.g., analogy method to make cost estimate using costs of similar existing products or system) [14, 15] could be used. In LCCA, short-term costs such as design and establishment of the initiated project or product and long-term costs such as operations, utilities, and maintenance costs should be considered appropriately [16].

3.1.1 Scope, purpose, and system boundary of LCCA

In an LCCA study, the scope, purpose, and system boundary of the system to be studied should be defined. In this chapter, the scope of LCCA study was limited to PtE value chains of almond and peach tree pruning. The purpose was to assess the cost effectiveness of pruning biomass supply chains with almond and peach tree pruning supplied in the form of chips in Spain. It was intended to develop LCCA methodology for evaluation of PtE initiatives, identify the cost-efficient design, development, and implementation of pruning biomass logistics configurations that could be benchmarked and applied different PtE initiatives in the same region or beyond.

The system boundary of LCCA of almond and peach tree pruning biomass includes core stages such as harvesting (collecting the pruning residue), processing, storage, transport, and management of the entire pruning biomass supply chain (see **Figure 5**). Almond and peach tree growing and pruning activities were not included due to limitation of data. Similarly, at power plant, power plant installation and plant operation costs were not included. The system boundary could be considered also from period over which an investment or LCC assessment is to be analyzed. The economic life (life span) of farm machines such as tractors is often considered to be 10–12 years during cost estimation [17]. Therefore, 10 years was considered for LCCA of almond and peach PtE value chain under consideration. Defining functional unit cost (FUC) is also important during defining the system. FUC is important for LCCA in order to harmonize cost data obtained from cost data inventory (expressed in different units). In case of PtE value chain, FUC could be expressed in Euro per ton of biomass (€/t) over a wet basis (w.b.). This should be done with caution, because the weight of biomass varies along the supply chain.

LCCA considers both capital cost (initial expense) and future expenses. Initial expenses are one-time start-up costs (initial investment costs). The future expense consists of different operational (e.g., labor, maintenance and repair), disposal cost at the end of life span and contingency costs. The disposal cost could be incurred at different stages of PtE value chain (e.g., harvesting, storage, transport) and management activities. For instance, there could be disposal of machineries and tools at farm or storage, dismantling of structures such as storage site, disposal of equipment from power plant after useful life span. It is important to note that, in some cases, the machineries, equipment, and facilities could have

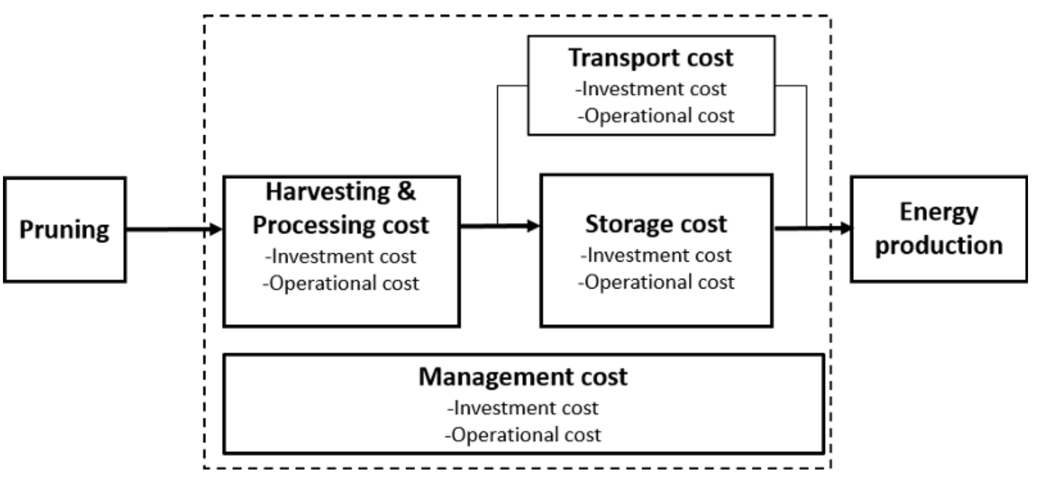

Figure 5.
Illustration of system boundary defined for this LCCA study of almond and peach PtE value chain.

some salvage value rather than incurring disposal cost, which could be considered as income (i.e., selling at price equal to estimated salvage value). Future expenses could also include environmental damage costs (e.g., emission costs) when standard monetary expressions (e.g., € per ton of CO_2) of environmental impacts are available. In this study, environmental damage costs were not considered as it requires more data and time to deal with its complexity, especially which environmental parameters to consider and which ones to omit is more complex, and was out of the scope of this study.

3.1.2 Remaining value

The purchasing price (list price) of machineries and equipment (see **Table 2**) could be considered as investment cost at the beginning of the PtE initiative, while the remaining value (RV) after depreciation over project life span could be considered as an income at the end of project service life. In order to estimate the RV at the end of project lifetime, i.e., 10 years, depreciation estimation approach can be used. In this study, remaining value and salvage value are not necessarily equal. Salvage value refers to actual economic service life of a machinery (or other equipment), say 15 years, while RV refers to only project lifetime e.g., 10 years of service life of the PtE initiative under consideration. Therefore, RV could be greater than salvage value in some cases. Eqs. (1) and (2) could be used to calculate the economic depreciation rate and RV.

$$D = \frac{LP - SV}{Ys} \tag{1}$$

$$RV = LP - 10 * D \tag{2}$$

where D is the depreciation cost in €/year; LP is the list price (purchase cost); SV is the salvage value at equipment economic life span of Ys; and RV is the remaining value at 10 years of project life span.

Item description	**Quantity**	**Purchase price**	**Annual working time**	**RV**
	Number	**€**	**h**	**€**
Harvester/chipper	1	30,000	800	9000
Harvester/baler	1	28,000	800	8400
Windrower	1	2700	800	756
Tractor (for chipping/baling activities)	1	61,000	800	21,960
Trailer	1	14,000	1000	0
Chipper (at storage site)	1	150,000	800	37,500
Tractor for loading and other activities (with shovel for loading biomass)	1	61,000	1000	21,960
Regular telescopic handler	1	58,000	1400	14,500
Truck with 90 m^3 mobile floor (trailer)	1	144,000	2000	28,800
Smart system for coordinated management	1	5800	1400	0

Table 2.
Investment cost and some related basic data of machineries and equipment.

3.2 Identification and description of costs along PtE value chains

The major components of operating costs to be considered in this study have been depicted in **Figure 5**. These include collection (harvesting) cost, storage cost, transport cost, and management (coordinated administrating and monitoring the PtE system) cost. The biomass production (cultivation) and pruning activities were not part of cost assessment in this study. Rather, the focus was how to use the pruning residues for energy generation instead of leaving them on soil or being mulched. Therefore, biomass production and pruning activities are out of the scope of this cost analysis. Costs of operational activities at the power plants are also out of the scope of this analysis (see **Figure 5**).

3.2.1 Harvesting and processing cost

The harvesting and processing (chipping) cost includes costs incurred during harvesting of pruning from arm field using machine. Costs related to on-farm activities such as chipping, on-farm transport, and on-farm temporary storage are considered as part of harvesting and processing cost. If the pruning should be collected from different fields, the average of costs from at each field could be considered.

3.2.2 Pruning biomass storage cost

Costs incurred at off-farm storage stage could be the initial cost such as construction of the storage and land cost while future variable costs at storage could comprise costs of handling and processing (e.g., chipping process at off-farm storage), truck unloading and loading, pile construction, and dismantling activities. In some cases, costs of sampling and quality analysis could be added (but not included in the case of almond and peach tree PtE value chain under consideration). In the case where the trader (owning the storage) could have multiple suppliers and receivers of pruning biomass, optimal location of storage site is required to reduce logistics costs. Storage cost depends on volume of pruning biomass stored and operational activities at the site. For the almond and peach pruning case, land cost is excluded from storage cost assuming that land can be obtained freely to promote renewable energy development from biomass.

3.2.3 Pruning biomass transport cost

The transport cost consists of fixed transport costs (e.g., investment on truck and trailers) and variable transport costs (e.g., operating cost during transport from farm to off-farm storage and from storage to power plant). The FUC of transport was euro per ton of biomass transported (€/t), and the FUC value could vary for different transport distances. From the survey of 25 PtE value chains [10], it was learnt that the average distance between farm and off-farm storage is about 14 km while the average distance between off-farm storage and power plant (end users) is about 116 km. As a basic scenario, the FUC was determined for 50 km average transport distance (i.e., 100 km round trip) from farm to power plant. The off-farm storage was assumed to be placed in middle way between farm and power plant. The truck facility location and off-farm biomass storage were assumed to be the same, and the truck starts from its location (storage) and returns back to storage after each trip. In addition, the capacity of truck used to transport pruning biomass was assumed to be 90 m^3 with payload of 24 t. The influence of transport distance on cost could be investigated through sensitivity analysis. Sensitivity analysis could be done also to investigate the influence of discount rate and truck capacity (volume and/or load) on LCC values.

3.2.4 Cost due to pruning biomass loss

Pruning biomass loss could occur during harvesting, storage, loading, and unloading activities. However, at the farm level, only biomass losses after the harvesting activity (e.g., handling during on-farm storage and loading for transport) were considered in the case of almond and peach. At off-farm storage site, all biomass losses have been considered. Except the biomass loss during loading, material loss during transport was considered to be negligible. For pruning in form of chips, the values used in calculation were 3% and 10% for on-farm loss and loss at storage stage, respectively. The loss at on-farm level is material loss at delivery to off-farm storage in reference to amount harvested. The loss at off-farm storage is the loss at the end of storage in reference to biomass weight at the start of storage. For pruning biomass processed in the form of bales, the loss is often less than the case of chips, i.e., about 2.5% and 1.5% for on-farm and storage stages, respectively. Due to the reduction of biomass weight at end of storage, it is important to consider the bulk density difference.

3.2.5 Pruning biomass supply chain management cost

In the case of almond and peach PtE value chains under consideration, the pruning biomass supply chain was managed by central management unit supported with smart system (see **Figures 3** and **4**) [11, 18]. Therefore, the management cost includes costs related to the management of biomass flow and product traceability information flow including marketing cost (e.g., cost of procurement and order management). The average cost can be estimated in €/t considering the total management cost during the year and the product delivered to end user during the same year. The management cost includes also the investment and maintenance cost of smart system and cost of providing appropriate training and technical support to all actors using the platform integrated in the smart system.

3.2.6 Calculating life cycle cost

For this coordinated management system, the total cost including cost of harvesting, storage, transport, and management could be modeled as indicated by Eq. (3).

$$LCC = H_c + S_c + T_c + M_c \tag{3}$$

where LCC is life cycle cost in €/t; H_c is harvesting cost in €/t; S_c is storage cost in €/t; T_c is transport cost in €/t; and M_c is management cost in €/t. For the case of almond and peach, costs due to biomass losses have been included into harvesting cost and storage cost. During cost calculation, FUC should be determined with caution due to variation of biomass moisture content. This model (Eq. (3)) could be used to determine either only the total operating cost or include the investment costs incurred at each stage of life cycle and expressed in €/t.

LCC values were calculated in the present money value, considering project lifetime of 10 years. Present value (PV) of payments to be made at future times can be determined using discount rate as given below (Eq. (4)) [19].

$$PV(i,N) = \sum_{i=1}^{N} \frac{C}{(1+r)^y} \tag{4}$$

where PV is the present value of total expenditure over N-year period; C is expenditure during year y; N is the lifetime of the system (years); and r is (real) discount rate (e.g., 5%).

Species	Country	Logistics description			
		Harvesting stage	**Transport to storage**	**Storage**	**Transport to end user**
Almond	Spain	Chipping in big bags	Chips in big bags	Pile of chips	Loose chips
Peach	Spain	Chipping in big bag	Chips in big bag	Pile of chips	Loose chips

Table 3.
Almond and peach pruning biomass and description of processing and handling.

Species	Country	Pruning potential prior to harvesting	Average material capacity*	Harvester working hours	Yearly potential [t]
		(t/ha)	**t/h**	**h/year**	**t/year**
Almond	Spain	0.62	0.63	800	504
Peach	Spain	2.64	0.77	800	616

**Harvesting capacity of the harvester in ton per hour.*

Table 4.
Harvestable quantity of pruning biomass during 1 year.

Where income data is available, net present value (NPV) could be determined (i.e., inflow cash minus outflow cash). In this case, the cost calculations were done for almond and peach tree PtE value chains for clearly defined system boundary. The processing and handling of biomass and harvestable quantity have been presented in **Tables 3** and **4**, respectively.

4. Results and discussions

Table 5 presents the calculated LCC values for almond and peach PtE value chains within the defined scope. In the analysis, weight over wet basis at the moisture content of starting of the storage construction was considered. Based on the bulk density at different duration along the pruning biomass supply chain, the weight at different stages has been converted to weight at the beginning of off-farm storage (in wet basis). The analysis results indicate that the harvesting stage was cost of hot-spot stage of the pruning biomass value chain, followed by storage stage. However, this was only for the case of 50 km transport distance considered. Therefore, if the transport distance increases, the transport cost could exceed the storage costs due to the increased logistics cost. For almond case, the cost at harvesting stage was about 83% of the total LCC (126 €/t) while it was about 82% (of 115 €/t) in the case of peach pruning. The main cause of high harvesting cost could be the poor harvesting performance for almond and peach tree pruning, i.e., 0.63 t/h and 0.77 t/h, respectively, when expressed in harvestable biomass quantity per hour (see **Table 4**).

Even though project lifetime of 10 years was considered, the calculated LCC values were presented in present money value at base year of 2016. In this type of cost assessment, besides the costs, income and net values (cost less income) could be determined. The main sources of income include the selling of pruning biomass in terms of chips, the avoided cost (i.e., cost of pruning handling by farmers, e.g., avoided mulching cost), and residual value at the end of project time. During the period when data of this study was gathered, the average selling price of chips was

Life cycle stage	Almond tree pruning			Peach tree pruning		
	Investment cost	Operating cost	Sum	Investment cost	Operating cost	Sum
Harvesting	30.92	74.09	105.01	25.44	69.03	94.47
Storage	0.46	8.60	9.06	0.52	8.92	9.44
Transport	0.58	3.51	4.09	0.47	4.30	4.76
System management	1.15	7.04	8.19	0.94	5.76	6.70
Total	33.10	93.25	126.35	27.36	88.01	115.37

Table 5.
LCCA results in €/t including the investment and operational costs.

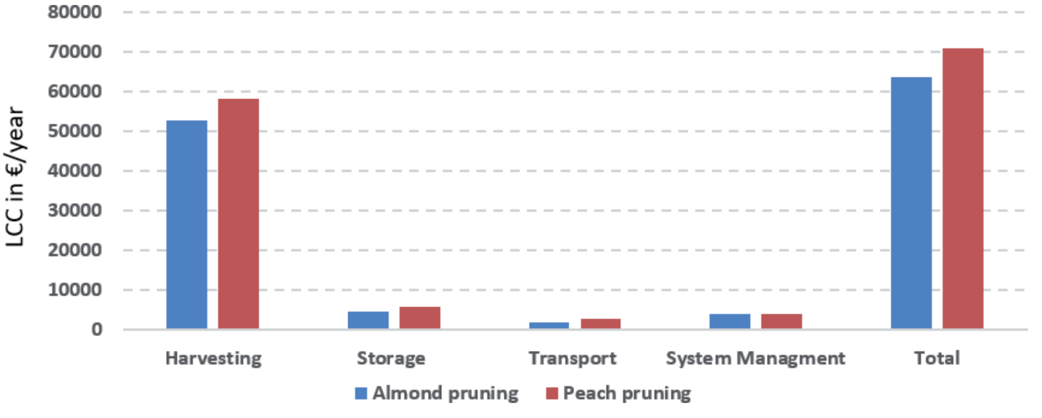

Figure 6.
LCC values in € per year, i.e., considering 504 t almond and 616 t of peach pruning biomass per year, 50 km transport distance from farm to power plant, and 90 m³ truck capacity.

about 64 €/t for both almond and peach pruning chips while the avoidable cost at farm was estimated to be 75 €/t on average.

When the quantity of almond and peach pruning biomass to be handled at off-farm storage during a year is known as indicated in **Table 4**, the LCC values could be determined in €/year as indicated in **Figure 6**. In this case, the yearly costs included both investment and operational costs (see **Figure 6**). From **Table 5** and **Figure 6**, it is clear that the operating cost is higher than investment cost in both almond and peach pruning cases. Considering the final LCC values, the share of operating cost was 74% and 76% for almond case and peach case, respectively. Therefore, more attention should be given to improving the operating (e.g., efficient harvesting machines) and management systems (e.g., smart tools for management and monitoring biomass flow) to reduce the operational costs, increase the economic performance, and promote the PtE initiatives.

5. Conclusion

Biomass from agricultural residue such as almond and peach tree pruning has significant potential as renewable energy resource, which enables to reduce the use of fossil fuels and contributes to sustainable energy use. Therefore, cost-efficient biomass processing and supply are very important to strategically plan and implement more sustainable energy production from biomass including agricultural residues. In this chapter, the cost of pruning to energy (PtE) value chains has been investigated using the case of almond and peach tree pruning with data from Spain. The life cycle cost analysis (LCCA) approach was used considering both investment and operating costs over the project lifetime of 10 years, while 2016 was the base year. First, the typical PtE value chain has been described. Then the scope and framework of LCCA study have been defined. In this case, harvesting (collection of tree pruning from field) and chipping, off-farm storage of chips, biomass loss at harvesting and storage, transport, and coordinated management of the entire pruning biomass supply chain have been considered. In the cost estimation, the pruning (cutting branches) activity and costs at power plant stage have been excluded due to lack of appropriate data. As a basic scenario, 50 km transport distance (from farm to power plant) and 90 m^3 truck capacity have been considered for both almond and peach cases. In the investigated cases, the yearly harvestable quantities have been 504 t and 616 t per year for almond and peach pruning, respectively. Accordingly, the yearly cost was calculated to be 63,680 € and 71,070 € per year for almond and peach cases, respectively. In terms of functional unit cost, the life cycle cost was calculated to be about 126 €/t for almond pruning and 115 €/t for peach pruning. In both cases, harvesting stage was found to be cost of hot-stage followed by the storage stage. The cost at harvesting stage was about 83% of the total LCC (126 €/t) in the case of almond, while it was about 82% (of 115 €/t) in the case of peach pruning. Similarly, the share of operational cost was found to be higher than investment cost. Considering the final LCC values, the share of operating cost was 74% and 76% for almond case and peach case, respectively. Therefore, at strategic level, more attention should be given to improvement of logistics operations and management in order to increase the economic performance of such PtE initiatives.

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