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Modern Animal Traction to Enhance the Supply Chain of Residual Biomass

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Abstract: Throughout history, the use of animals for agricultural and forestry work has been closely associated with human societies, with multiple references to animal power being utilized for various tasks since the Neolithic period. However, the advent of industrialization has fundamentally transformed the reality of society, leading to a significant shift towards the mechanization of processes. Despite this, animal traction continues to play an important role as a workforce in many developing countries and developed nations, where there is a renewed interest in the use of animal traction, particularly for tasks intended to have a reduced environmental impact and a smaller carbon footprint. The present study conducted a SWOT analysis to examine the potential of animal traction as an alternative for the recovery processes of forest residual woody biomass, particularly when the use of mechanical equipment is not feasible. This can contribute to the creation of value chains for residual products, which can be harnessed for energy recovery. The utilization of modern animal traction can promote the sustainable development of projects at the local and regional level, with efficient utilization of endogenous resources and the creation of value for residual forest woody biomass. This approach can thus facilitate the optimization of supply chains, from biomass to energy.

Keywords: modern animal traction; residual forest biomass; sustainable forest management; biomass energy recovery; forest biomass supply chain

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1. Introduction

The supply chains associated with forest management processes comprise a set of tasks that can contribute to the viability of the whole set in a positive or negative direction [1]. Depending on their viability, some tasks can make the process so inefficient that the entire supply chain is called into question [2–4]. This situation is more critical the lower the value of the products to be managed, such as residual forest biomass [5]. Residual forest biomass supply chains intended for energy recovery comprise, from the outset, a set of constraints that can make the entire process unfeasible [6,7]. For example, the spatial dispersion of materials, their low density, their low calorific value, and their heterogeneity affect tasks such as the transport between the place of production/generation and the place of use, often making the process of valorization unfeasible [7,8]. The entire supply chain of forest residual biomass can be divided in three stages/tasks, as shown in Figure 1.

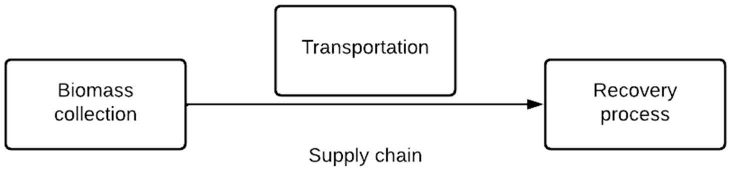

Figure 1. Simplified composition of the steps associated with a residual forest biomass supply chain for energy recovery.

Each of the stages can also be divided into subtasks, and for some their viability is directly associated with the constraints characteristic of this type of material. In this way, each step can be subdivided, as shown in Table 1.

Table 1. Subtasks of the residual forest biomass supply chain for energy recovery.

Collection	Transportation	Recovery
Tree cutting Cutting branches and treetops Debarking Biomass forwarding [1] Formation of the log loading spot	Loading Transport Unloading	Preprocessing [2] Processing

[1] Biomass forwarding consists of moving wood trunks, tree branches, or other residues from forest exploitation, to concentrate them along the extraction trails for later transportation. [2] This includes operations such as shredding or drying.

In a first analysis, distinctive aspects such as the density, heterogeneity, and spatial dispersion in a given area will influence how the supply chain stages occur. However, this influence will be of particular importance in the subtask “biomass forwarding” of the “collection” stage, which consists of grouping the residual biomass that results from the “cutting” and “cutting branches and treetops” process in a given location. In other words, the residual biomass dispersed throughout the area where the forestry management operations take place must be collected and transported to a place where it can later be collected for recovery [9–11]. However, this process can be even more complex; the more dispersed the biomass, the more heterogeneous the materials, the greater the variation in the density of the materials, and, mainly, the more complex the conditions of the land where the plants are developed; namely, the orography, waterlogging conditions, and the density of stands, but also the natural value and sensitivity of the area, which conditions or prevents the use of conventional methods of forest exploitation [9,12,13]. Concerning the solution to the constraints presented by the density and heterogeneity of the materials, the use of processes such as pre-loading shredding, or baling allow the optimization of the subsequent stage, the transport, by contributing to a standardization of the materials to be transported and an increase in the bulk density of the products [14–17]. That is, the mechanization of processes contributes to the optimization of the logistical process through the increase in density and improvements introduced to the format [18]. However, concerning the “biomass forwarding” subtask, in which mechanization could easily be indicated as the immediate solution, this is usually not possible, due to the operating conditions on the ground [19]. The steep slopes that frequently occur, associated with the risk of the machines jamming, and the difficulty in maneuvering the equipment caused by the existence of natural obstacles and the density of forest stands, contribute to the fact that the mechanization of the biomass collection process residual is often not possible, or that it is too costly [20–22].

In this perspective, the use of alternative solutions, such as modern animal traction, defined as the use of animals to carry out transport and traction work, in which animal welfare is a priority and where the intention is that the tasks carried out have the lowest possible environmental impact, presents itself as a possibility, since this is a solution that allows counteracting some of the constraints presented and that contributes to the viability of very important stages of the supply chain for residual forest biomass. The main objective of this article is to present the current state of the art on the use of animal traction in operations associated with forest management, through a review of the available literature, but also to present the main advantages, difficulties, threats, and opportunities resulting from the use of this alternative, with the realization and discussion of a SWOT analysis.

2. Literature Review

The use of animals to help carry out heavy activities has been constant throughout human history [23]. Since time immemorial, animals have been domesticated to satisfy the basic needs of human communities [24]. For example, in the initial phase, human beings realized that the breeding of certain species could meet food needs, avoiding hunting in times of greater adversity, such as the winter period, and when prey was scarce for whatever reason (migration, diseases, excessive predation, . . .) [25,26]. In this way, humans ensured that certain species lived under their protection and care, providing easier access to their meat, milk, and eggs for food and their skins, wool, bones, and frames for making tools and clothing [27]. On the other hand, the domestication of increasingly large animals, such as cattle and horses, led to their being used to carry out tasks in which the physical strength of animals would supplant that of humans, as is the case of transporting people and goods, but also in carrying out tasks with the advent of agriculture [28]. Thus, animal power has followed the evolution of humanity since communities became organized, even if itinerant, but mainly since they have settled and agriculture became the most relevant activity for the sustenance of populations [29].

This reality, which persisted for thousands of years, saw a decline with the industrial revolution and the mechanization of processes [30–34]. The animals, seen as an asset that contributed to the community on several fronts, namely through the workforce they represented, but also because they were a permanent reserve that could be sold or exchanged for other goods or even because they represented a reserve of food for times of greater need, moved, with mechanization, to a second plane of interest [35]. Motorized equipment represented a very significant increase in productivity without the need for the care that animals required, such as their protection, care, and food [36]. In this way, animals slowly lost their importance as an engine of rural development, despite the logistical system of transporting people and goods continuing to depend on animal traction [37]. Currently, the use of animal traction continues to be a reality. Animal traction today plays different roles from country to country, which can be divided into three types: (i) in developed and industrialized countries, animal traction has been practically abandoned; (ii) in developing or emerging economy countries, animal traction tends to be replaced by mechanical equipment, such as tractors and other agricultural machinery; and (iii) in less developed countries, animal traction often continues to be the only energy source available for carrying out heavy work, in addition to manual work. According to data presented by the FAO, approximately 400 million animals (cattle, horses, camelids, elephants, . . .) are used to carry out tasks (agriculture, forest management, . . .) and to transport people and goods (Figure 2) [38–42].

In certain regions of the world, a significant part of the energy spent on agricultural work continues to be expended by the farmers themselves (manual work). According to statistics from the FAO [43], the forms of energy used in carrying out agricultural work are distributed as shown in Figure 3.

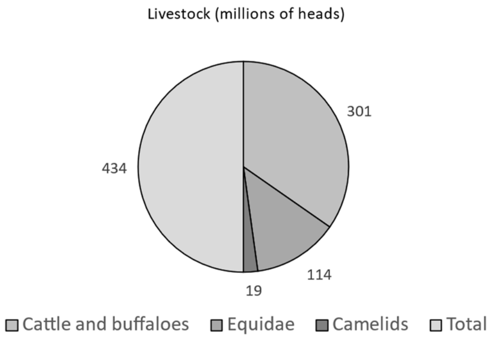

Figure 2. Number of animals used for work in the world, according to estimates by the FAO (adapted from [43] referring to data earlier than 2011, which are the only data that could be found in the literature).

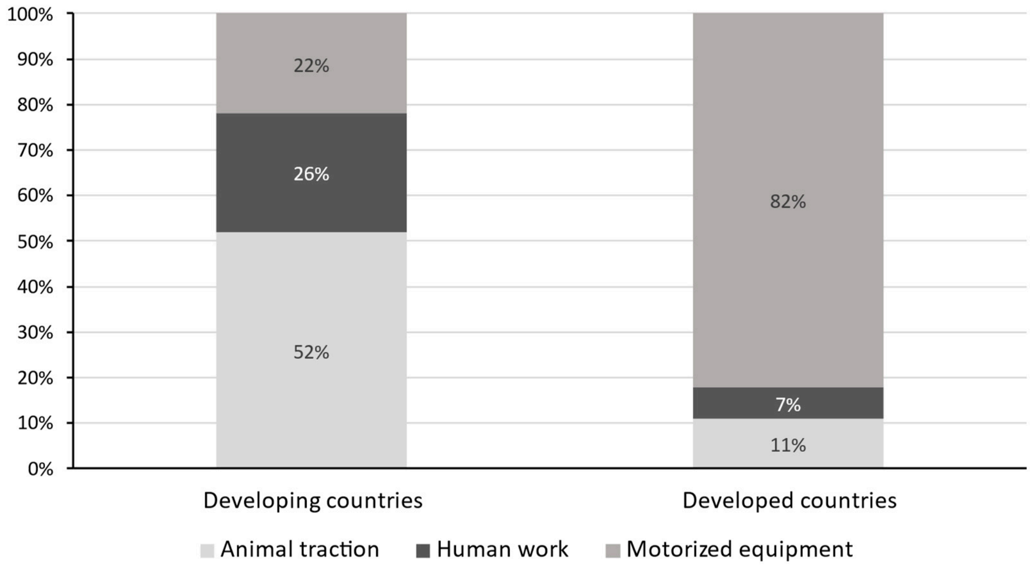

Figure 3. Distribution of different forms of energy used in agricultural work in developed and developing countries (adapted from [43]).

On the other hand, in developed countries, namely in Central and Northern Europe, the use of animals in agricultural and forestry work has always persisted, with this practice reaching a high degree of development and innovation. An increasing number of small and medium-sized farmers and forestry owners in these regions, who are very dedicated to the sustainable exploitation of natural resources, have already realized the potential of using modern animal traction, as demonstrated by the work of several authors [44–46].

The current concern with the sustainability of processes has led to a growing interest in animal traction as a tool for carrying out agricultural work and forestry management, mainly associated with local valuation processes. Rodrigues et al. [46], in a study carried out specifically with a focus on mountain regions, highlighted the increasingly relevance of public opinion about the need to reduce excessive mechanization and industrialization of agricultural practices and the exploitation of forest resources, mainly due to the environmental impacts entailed, leading to the use of animal traction once again being considered as a valid and current source of energy. These authors point out, as the main advantages of this practice, that the animals transform the biomass that they feed on into energy (used in work) and fertilizer, which prevents soil degradation, and, in this way, contributes to sustainable management of arable land, forests, and sensitive areas. Other authors, in a line of investigation focused on the analysis of the value of endogenous and small-scale resources, as is the case of Johansson et al. [47], analyzed the impact of animal traction on food production in a Swedish small-scale integrated organic farm, where they concluded that this practice maintains, in a global way, the same productivity compared to mechanical means using fossil energy. However, the use of animal traction is not limited to small-scale farming or forestry, since the lower impact of animals on the soil and surroundings where the tasks are carried out has been pointed out as one of the main advantages of animal traction as an alternative in environmental recovery processes. As demonstrated by Kayombo and Lal [48], the soil compaction process is more intense the longer the duration of action on the soil. The authors claimed that, whether natural or anthropogenic, induced soil compaction has detrimental effects on the growth and yields of a wide range of crops and exerts the same impact on the recovery of natural vegetation. Thus, according to the same authors, as well as other authors such as García-Tomillo et al. [49], Santos et al. [50], and Figueiredo et al. [51], since compaction can persist for a long time if no adequate measures are taken to minimize or alleviate it, the use of means with less impact, such as the use of animals as a workforce, effectively contributes to minimizing the problem of soil compaction.

3. SWOT Analysis

SWOT analysis is a tool used for defining strategies and planning, where strengths, weaknesses, opportunities, and threats are presented and recognized as internal and external factors that can positively and negatively affect projects. In the specific case presented here, a SWOT analysis was applied with the assumption that the use of animal traction is a viable alternative methodology for optimizing processes of a logistical nature for the recovery of residual forest biomass for energy recovery, as presented in Table 2.

Table 2. Strengths, weaknesses, opportunities, and threats associated with the use of animal traction as an operational tool for optimizing the residual forest biomass supply chain for energy recovery.

Strengths
• Less environmental impacts than heavy machinery. • Fewer losses due to damage caused to the trees in forest stands compared to those that occur with heavy machinery. • Smaller carbon footprint by replacing equipment that uses fossil energy. • Possibility of recovering residual forest biomass inaccessible to collection with mechanical equipment. • Increasing amount of residual forest biomass available for energy recovery. • Competitiveness in uneven aged silvicultural systems based on selective cutting. • Flexibility and possibility of developing complementary or additional tasks for biomass extraction.
Weaknesses
• Lack of qualified operators with experience in driving animals to perform different tasks and in different environments. • Lack of trained animals to perform traction tasks. • Lack of animal trainers to carry out traction tasks. • Lack of trainers to enable operators. • Lower productivity of the human–animal binomials compared to mechanical equipment when terrain conditions allow their use and when there are no operating restrictions. • Possibility of work-related accidents involving animals. • Logistical difficulties associated with transporting animals and their accommodation, protection, and feeding in the workplace.

Table 2. *Cont.*

Opportunities
• Development of tools to support forest operations, which can be created and implemented to the exact extent of needs and adapted to each specific situation, creating an additional service based on craftsmanship, which will also contribute to the creation of new job opportunities in rural areas. • Possibility of using indigenous breeds of cattle and equids better adapted to local conditions, where there is already knowledge about the care, maintenance, and breeding of these animals. • Contribution to the preservation of native breeds by increasing the demand for animals traditionally used in agriculture and forestry. • Restoration of agro-silvo-pastoral management models through the recovery of traditional practices updated and adapted to the new business reality. • Creation of new business models for providing services in rural areas. • Creation of new value chains for residual biomass inaccessible to mechanized collection. • Establishment of sustainable management models at the local scale, simultaneously addressing environmental (ecological impacts, energy efficiency, GHG emissions, incorporation of organic matter into the soil), economic (incorporation of positive externalities, regional development), and social (appreciation of work with animals) dimensions. • Increasing local/regional/national energy self-sufficiency.
Threats
• Difficulty in achieving the scale required for the industrial feasibility of the process. • Possible opposition from animal rights movements, with allegations about exploitation, mistreatment, and other considerations related to animal welfare. • Non-recognition of modern animal traction as a tool for local and global sustainable development by policy makers. • Non-inclusion of modern animal traction in local development strategies and policies. • Lack of interest from academia in this issue. • Extinction of traction animal breeds.

4. Discussion

Animal traction as a tool applied to the execution of tasks included in the supply chain of energy recovery from residual forest biomass presents a set of factors that influence the success or failure of the option chosen and which are internal or external to the process itself. That is, some factors are inherent to the process itself, which correspond to its strengths and weaknesses and depend solely on the characteristics of the option chosen and the variables involved. On the other hand, there is a set of factors that correspond to the opportunities and threats that may result from choosing this option and are external to the option itself. That is, they depend on factors that are not controllable by the project but that can positively or negatively influence the entire project. Figure 4 schematically presents the relationship between a project's internal and external factors and how they can positively and negatively affect that project.

The factors that positively and negatively affect the project must be balanced. In this case, concerning the analysis of strengths and weaknesses (Table 2), while internal factors influence the option of using animal traction in the supply chain processes of energy recovery from residual forest biomass, there is a relative balance between positive and negative factors. In fact, with the identification of the factors for strengths and weaknesses, it is not possible, at first sight, to say that there is a clear advantage of one side over the other. If, on the one hand, the environmental advantages seem to assume a leading role, the issues considered as strengths and related to aspects of an economic nature should, in the end, acquire greater weight at the time of decision-making. In this field, the possibility of valuing residual forest biomass that was inaccessible to collection using mechanical means and contributing to increasing the amount of residual forest biomass that is available for energy recovery allows the reorganization of the management of available resources, enhancing the optimization of their recovery and contributing to a more significant amount of residual forest biomass being valued. However, the internal negative aspects identified seem to be sufficient reasons to jeopardize the success of the evaluation of the whole process, since they contribute significantly to the increase of risk when making a decision. There seems to be, on the part of policymakers, academia, and even non-governmental organizations (NGOs), a lack of attention and interest in animal traction as a tool that contributes to sustainable development, which has caused a delay in the progress of scientific research on the subject and even in the dissemination of the practice, which is still somewhat seen as a sign of underdevelopment [52].

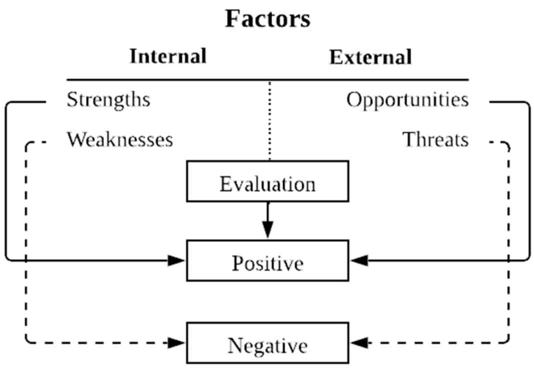

Figure 4. Contribution of internal and external factors to project development.

On the other hand, the positive externalities, from the perspective of new opportunities, seem to indicate a set of possibilities that may be decisive when deciding on the option of using animal traction as a tool for carrying out tasks within the supply chain of energy recovery from residual forest biomass. The issues identified as opportunities, both from the perspective of creating new business opportunities and creating new value chains for materials that were not previously valued, can strengthen arguments of an economic nature, which acquire particular importance because these activities take place in rural areas, where usually the potential for adding value to products and creating value chains is not abundant. The external threats identified do not seem to pose real obstacles, except for the difficulty in creating the scale to achieve supply capacity at an industrial level.

In addition, the use of animal traction can be highly competitive in silvicultural systems based on selective felling, such as those in uneven-aged stands. On many occasions, these systems are not applied simply because management operations cannot be carried out with machinery, due to access, maneuverability, and performance problems. From the analysis of these factors, the option of using animal traction in the execution of tasks in the supply chain of residual forest biomass for energy recovery can be presented as being currently in a situation of slow implementation, despite having been the driving force of the development of societies in the past. As seen in the results presented in Table 2, the weaknesses identified are precisely related to aspects that can be considered derived from an alleged forgetting of knowledge that accompanied humanity over thousands of years, but which was lost due to the advent of mechanization. Dependent on human's close relationship with certain animal species, the loss of this knowledge remains latent, since there is still a specific memory about the modus operandi, which may be reawakened. In the case of Portugal, operator qualification is ensured by APTRAN—Associação Portuguesa de Tração Animal, which provides training actions throughout the national territory, and by IPB—Instituto Politécnico de Bragança, which for the first time has included an animal traction curricular unit on a higher education course.

Using animal traction in a forest environment obeys a set of assumptions that lead to tasks being carried out more efficiently. For example, after felling, the tree must have its branches cut completely, and the trunk must be cut into a wedge to reduce the effort required of the animals caused by possible points of friction on the ground, as it can function as an anchor, as shown in Figure 5. In this way, it is possible to avoid the need to build sledges, such as those developed for the work carried out under the LIFE in Common Land Project (available at https://www.lifeincommonland.eu, accessed on 21 December de 2022), whose main objective was to improve the conservation status of the wetlands in the Serra do Xistral Special Conservation Zone (Natura 2000 Network of Northern Galicia, Spain) [53].

(**a**)

(**b**)

Figure 5. Operation of cutting, pruning and carving trunks to be transported using animal traction carried out in a demonstrative action by the Rural Laboratory of Paredes de Coura within the scope of Rural Camp 2022 (Paredes de Coura, Alto Minho, Northern Portugal). (**a**) Carving the logs; (**b**) transportation of biomass.

These apparently less important issues contribute to increased productivity by reducing the effort made by the animals, and in this way, contribute to the success of operations and to ensuring animal welfare. The value of this combination of empirical knowledge obtained through experience that still exists for this type of activity, and which although in decline in some regions may be very much alive in others, with new knowledge derived from current methodologies based on adapting traditional processes to new needs has been demonstrated by the number of organizations that in Europe are already dedicated to the promotion of animal traction. The list of European national entities registered with FECTU—Fédération Européenne du Cheval de Trait pour la Promotion de son Utilization (available at https://www.fectu.org, accessed on 21 December 2022) includes 22 members, showing the growing interest in modern animal traction.

The development of this new (recovered) knowledge will also incorporate all issues associated with animal welfare, making a difference for full compliance with sustainable development objectives. In this way, the new advent of sustainable forestry management has, in animal traction, a tool that will allow the use of a more significant percentage of resources, by creating new value chains and business models. At the current stage of development, it seems clear that animal traction will have a role to play in small-scale uses in short-distance supply chains, thus overcoming the identified weaknesses and threats. However, when disseminated and with the increase in operational units, this practice could also contribute to the availability of a growing amount of residual forest biomass for energy recovery, which over time could reach an industrial scale, if schematized as in Figure 6. Despite the difficulty in establishing relationships of scale that allow, for example, the supply of residual forest biomass to an industrial-scale energy recovery unit, this dimension could be achieved through the multiplication of collection units.

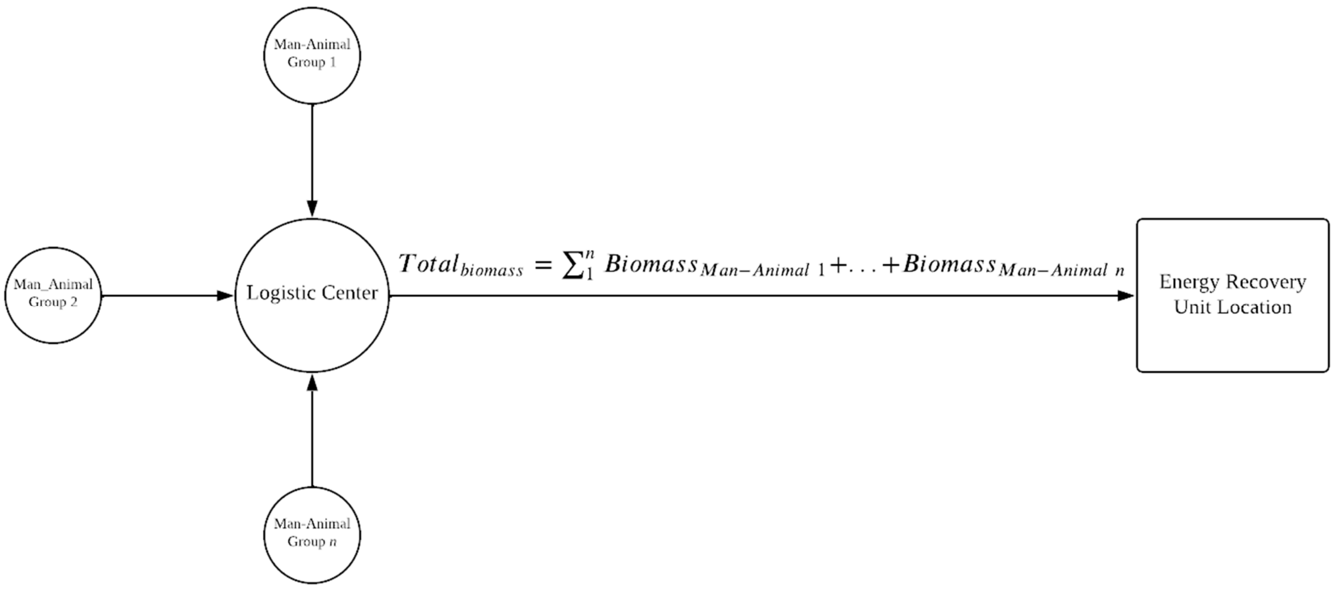

Figure 6. Residual forest biomass supply chain for energy recovery with biomass forwarding tasks to be carried out using animal traction.

As depicted in Figure 5, modern animal traction is envisioned as a niche solution for sustainable resource utilization, primarily in proximity to available resources and with established short supply chains. There is potential, however, for the development of residual forestry biomass recovery operations supported by a variety of small-scale units. The integration of these units can create a network for collecting resources that are not easily accessible through traditional mechanical means, making it feasible to install local processing units for these materials, albeit preferably of smaller sizes. Combining modern animal traction with mechanical equipment can further enhance its operating potential. For instance, residual biomass transported by animals to the loading zone can be shredded to optimize truck transport, increasing the bulk density compared to bales. Additionally, animals can be paired with forwarder tractors, which can transport materials over short distances to the point where the mechanical equipment is already capable of operating. This integration of animals and mechanized equipment would lead to increased productivity in the residual forest biomass recovery process and greater efficiency and sustainability in the supply chain.

5. Conclusions

Forest biomass supply chains intended for energy recovery often grapple with structural inefficiencies, largely precipitated by the challenges inherent in the collection phase within the forest itself. These complications arise, not only from the physical characteristics of the materials, but also from the impediments that hinder the maneuverability and operability of the typical mechanical equipment employed in the process. Contemporary animal traction emerges as a highly viable alternative to these issues, offering the potential to amplify operational efficiency, whilst concurrently diminishing environmental impacts. This method, thus, presents a significant contribution to sustainable development. As corroborated by the conducted SWOT analysis, the application of modern animal traction can feasibly enhance the viability of supply chains dedicated to energy recovery from residual forest biomass.

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