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Enhancing Agroforestry Residual Biomass Recovery: Developing and Validating a Supply Chain Management App-Based Model

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ABSTRACT

Due to climate change and agricultural activity changes, there has been an upward trend in burnt areas in various countries. Besides two essential factors to fire occurrence, a third may be considered: ignitions, which often happen due to negligent attitudes toward fire, frequently used to eradicate agroforestry leftovers. As a way of dealing with this type of incident and reducing the rural fire occurrence risk, there is a need to create destinations for these leftovers, promoting the residual biomass recovery, and avoiding fire ignition needs and fuel loads. In an internet and digital applications era, their use can be used as a driver to fill leftovers destination necessity, connecting the two market sides, the supply, and the demand. In this context, this study aims to consolidate an app-based model presented in previous studies through an expert's validation. As a result, an information model to foster the agroforestry leftover recovery, as well as requirements list for the digital artefact that will support this model, are presented. These results present a relevant integrated model where different various scenarios are proposed, offering different paths to fire risk mitigation and inherent sustainability concerns.

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1. Introduction

Geographically, various countries are being affected by wildfire occurrence [1], [2], such as the Mediterranean region [3]. In the last decade, around 2.8 million ha of land burnt, being 42% of them in Portugal [4]. In 2017, Portugal faced a scenario with 0.5 million ha of land burnt and more than 120 victims [5]. The wildfires impact infrastructures, economy and public health [6]. Despite the decrease of burnt land, due to the combat and prevention measures, it is expected that the wildfires quantity will increase in future [3], [5], due to climatic changes and prolonged droughts. Another reason associated to the wildfire occurrence increase relies on land abandonment [7]-[10] and afforestation. In this way, fuel loads are the main reason for rural fire occurrence, and, besides this, many people make agroforestry leftovers elimination, resorting to burning, which could result in rural fires [7].

To solve the above cited problem, the recovery of agroforestry leftovers, Residual Biomass (RB), may be the solution, avoiding fire usage and fuel load accumulation, acting in climate change mitigation, since RB may be used to produce renewable energy. However, the Residual Biomass Supply Chain (RBSC), the chain responsible for leftover recovery, presents various cons, where logistic costs are the main one [11]. RBSC is also characterized by the lack of communication and coordination between actors [11], where many landowners (who have the leftovers) do not have any conscience about biomass value and "must accept" the value proposed by the logger [12]. Analyzing this topic, it seems clear that there is a lack of systems/solutions that may avoid misinformation and transparency occurrences, making information channels a priority to foster RB recovery, and, consequently, reduce rural fire occurrence. In this sense, it raises the research question, of which information model should be adopted to boost the residual biomass recovery. The goal achievement will be made resorting to an expert validation of a preliminary information model and app concept [13], [14]. In this sense, the information model and application concept which supports the model will be evaluated, culminating in a new information model and in a more consolidated app concept to answer the model needs. The study was conducted in an inductive form, being the study conducted in Portuguese context with the aim of draw up general conclusions, replicable in different countries.

Section 2 presents the theoretical background. Section 3 presents the actual information model and the actual app concept, after that, conclusions obtained in the expert validation meeting (methodological approach), culminating with the new results obtained. Sections 4 and 5 present Discussion and Conclusions, respectively.

2. Theoretical Background

2.1 Rural fires problematic: the Portuguese context

Throughout the Mediterranean countries, it is possible to observe an increase in wildfire occurrence [15]. Portugal, a Mediterranean country, is not exempt from this trend, being possible to note a light tendency, between 1980 and 2017, for a growing amount of burnt area, having reached its peak in 2017 [1]. In 2017, the data states more than 0.5 million ha of burnt land and 117 lives lost [15]. According to Leone et al. [15], a wildfire could be understood as a pyro-convective phenomenon that goes beyond control, and where unpredictable propagation phenomena can be observed, causing negative impacts on the three dimensions of sustainability.

Some reasons that increase the fire hazard risk are weather conditions, associated with climate changes, such as heatwaves or little precipitation [7], which can lead to long periods of drought, causing new areas probably to have fires [16]. Another reason among European countries is land abandonment, which contributes to the fuel load growing on these territories [10]. Rural fire occurrence is also related to negligent attitudes towards fire, many of them stem from the use of these practices as a way of eradicating leftovers from agricultural and forest management activities [7]. The occurrence of these fires has challenged traditional fire management practices [15]. Among rural village residents, this challenge is visible because they usually have techniques for dealing with the fires. Agricultural abandonment and rural exodus among younger generations can contribute to a decrease in the natural protection of these environments [16].

There are two strong points to act on: climate change mitigation and fuel load reduction. One procedure that can be used to act in both ones is the recovery of RB, which is traditionally little used, burned or discarded [17]. Reducing the risk of fire can be a motivation to make this match happen [18]. Some works have studied different forms of recovery of these leftovers, such as the study of Nunes et al. [19], where the authors study the possibility of transforming a Portuguese coal station power into biomass station power, which can have a positive impact on the need to renewable energies, being a driver to the climate changes mitigation, acting also as a booster of rural fires decreases.

One of the major problems of the RB recovery entails logistic costs. Sometimes, monetary values inherent to biomass valorization, just cover the transportation costs, leaving, for example, the harvesting costs to the landowner [20]. The RBSC comprises four main stages, cutting, extraction, storage, and transportation [21]. These stages have inherent costs that make the process challenging and expensive [22]. Besides the costs, RB has some characteristics, such as high moisture content and low energy density, that could make less feasible the energy potential recovery [11]. Seasonality and geographic dispersion are other crucial constraints in RB recovery [23]. One of the greatest problems in RBSC in the Portuguese context is the lack of information and coordination between the various actors. This fact is visible in the landowner and logger communication, which is made resorting to face-to-face and telephone conversations, where in most of cases, the logger defines the RB valorization, and the landowner must accept under the condition of receiving 0 for the RB [12].

Optimization tools are necessary to diminish the logistic costs, to make the process more feasible and to potentiate the use of this resource, which could act as a potentiator of renewable energy and reduce the fire risk. Mathematic formulations to support decision-making processes, and optimizing RBSC, have been developed, such as the work of Moretti et al. [24]. However, the literature is a little scarce concerning the presentation of information channels (platforms) that, effortlessly, could potentiate the linkage between stakeholders, reduce misinformation and make the RBSC more appealing to the landowners that, in some cases, as monetary difficult to ensure the fuel management activities, these channels could generate additional revenues, mitigating costs inherent to forest management activities.

2.2 Supply chain information systems: benefits and validation importance

In modern worlds, enterprises are conscientious about the importance of Supply Chain (SC) digitalization with the major goal of attaining more competitiveness levels [25]. This could be explained by the number of real-time modifications that SC faces, which obligates that those become more secure [26]. Digital Tools (DT) have been used with the aim of increasing the sustainability and performance of enterprises [27]. One example of this is the work of Hammond et al. [28], where a study conducted in redeveloping brownfield land context, states that informative DT aid the decision-making process of the stakeholders.

Concerning the recovery of leftovers, promoting the circularity economy, DT, as well as circularity plans have worked as a driver to a low-carbon economy and a social development. In the building industry, digital platforms have been used to collect data about leftovers, promoting simplified communication among the SC stakeholders, acting as a collaboration center, making SC more reactive [29]. Concerning to agroforestry industry Geographic Information Systems have been crucial in the support of decision-making, aiding in inventory levels understanding and harvest estimation [30].

The concept of usability can be defined as the degree to which an item may be utilized by defined users to achieve specific objectives with efficiency and satisfaction in a particular context of usage [31]. This dimension could be evaluated resorting to usability evaluation techniques, that could be divided in three major categories: inquiry, inspection, and testing. Briefly, the first ones aim to perceive requirements and the system compression by the users, common techniques used in this evaluation are surveys, interviews or focus group. The second type of methods, the experts analyze the system based on experience and norms, which could be made resorting to heuristic evaluations. The last group, aims to test the platform with users, observing users and evaluating objective metrics, such as execution time or complete task rate, to validate the platforms [31]. Other studies, [32], evaluate the usability of platforms resorting to a test that incorporate task execution part, as well as post-test questionnaire, where Likert scale was used to perceive the usability and satisfaction of platform.

2.3 Sustainable Development Goals: concept and goals description

Aiming to the boost prosperity of future generations, the United Nations have launched an outline of 17 Sustainable Development Goals (SDGs) to improve human lives but also ensure planet concerns. As a focus, it may be highlighted questions such as poverty elimination [33], improvements in health and education or climate change mitigation [34]. Specifically the 17 SDGs are, SDG1- “No poverty”, SDG2- “Zero hunger”, SDG3- “Good health and wellbeing”, SDG4- “Quality education”, SDG5- “Gender equality", SDG6- "Clean water and sanitation", SDG7- "Affordable and clean energy", SDG8- "Decent work and economic growth", SDG9- "Industry, innovation and infrastructure", SDG10- "Reduce inequalities", SDG11- "Sustainable cities and communities", SDG12- "Responsible consumption and production", SDG13- "Climate action", SDG14- "Life below water", SDG15- "Life on land", SDG16- "Peace, justice and strong institutions" and SDG17- "Partnerships for the goals" (available at: https://sdgs.un.org/goals, accessed at 11th November 2024). Bioenergy (such as the energy from residual biomass) usage fosters the circular economy principles, and may have a significant impact on SDG attainment, namely in SDG7, because it allows electrical energy in populations where actually they do not have, in SDG9 because it fosters the economic growth, SDG12 and SDG13 because it promotes the circular economy, which can be understood as the transition from a mindset of consumption of limited resources to one of recovery, which emphasizes the elimination of waste [35], and climate change mitigations. In an indirect form, this recovery may promote the SDGs 1, 2, 4, 8, 10, 11 and 15 [36].

3. Goals and methods

3.1 Methodological approach and section structure

As already mentioned in Section I, the present work was based on a model and concept developed by the authors, which was subject to validation with experts in the field, in a Focus Group, as referred by other works in IS development stages [37]. Concerning Focus Group, the first step was to present the results developed in previous works, starting with the initial information model presentation, followed by the app concept presentation. After that, the experts were invited to comment, presenting lacks or challenges about the model. In the fourth stage, the experts were invited to present possible solutions, referring to different paths to the information flow. The results were recorded and, after that, were analyzed carefully to construct the new model. Ended the information model building, the app requirements list was revised, where some initial requirements were kept, others were modified, and a significant number of requirements were added.

This methodological process is illustrated, below, in Figure 1, where besides the tasks carried out in the methodological approach, the framework elucidates section 3 structure, explaining which highlights may be found in each section.

3.2 Input section – AS-IS information model and Platform presentation

3.2.1 AS-IS information model

The model (AS-IS model) that serves the recovery of biomass leftovers has a basis a marketplace logic, where producers could communicate their agroforestry leftovers (leftovers from agricultural and forestry activities) and this information would be used on the demand side by transporter and end consumers. Here the procedural model flow is linear, the producer communicates his/her leftovers, and these are collected by transporters who deliver them to the end consumer.

This would essentially be created to recover those traditional leftovers that are obtained from traditional forestry and agricultural management practices, which are often burned in the open and are the basis of some fires. The Figure 2 summarizes the procedural stages of leftovers recovery.

The following section will detail the platform that respond to this model, also there will be related each actor and their respectively.

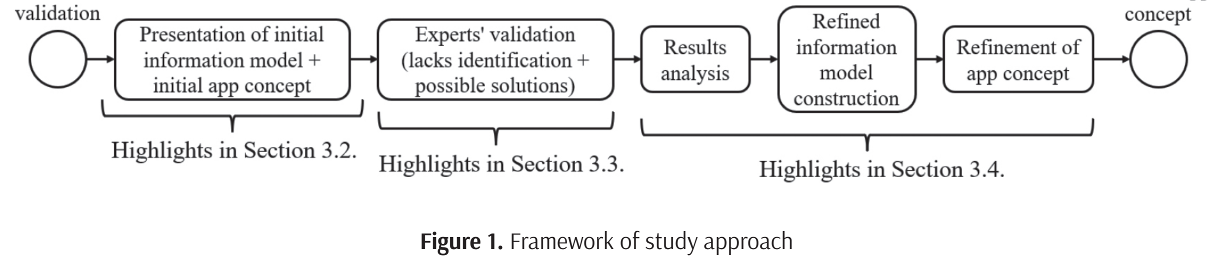

Figure 1. Framework of study approach

Figure 2. Simplified flowchart of the model considered in the previous proposed app

3.2.2 Platform presentation – tool concept

This section will detail the platform presented in [13], [14], which has the aim of response to the model described in Section 3.2.1. The platform tries to cover the three main players in this chain, the producer, the transporter, and the end consumer. In a briefly way, the producer represents all people who have agroforestry leftovers. These leftovers could arise, essentially, from two sources, from agricultural activities and, from forest management operations. In platform, this actor will have the possibility of communicating his/her leftovers, monitoring their status (whether they have already been collected or allocated to a route) and accessing financial information, resultant from the leftovers' valuation. The second actor, transporter, enters this platform as the connector of the other two, ensuring the transportation of RB. The platform will provide to transporter information about collection routes, or producer leftovers. The end consumer emerges in this platform to finish the entire RBSC. Concerning to the specific requirements, it is possible to state an aggregated information about historical loads, and financial transactions (being end consumer responsible to insert their information in system). End consumer should also communicate into the system which leftovers s/he accepts. These two last actors (transporter and end consumer) have the particularity of being able to communicate his/her availability window to make his/her services, transportation, or load reception. For the producer, this requirement was not important because the leftovers, in many cases, are disposed in roadsides, and can be collected at any hour.

Concerning to the benefits for each actor, the producer could attain a valorization to a typical "waste" that sometimes, s/he must pay to be collected, or, in most cases, s/he burns them in open air. The transporter could obtain more jobs, which in itself is beneficial as it is essential to any business, but s/he has the added advantage that all routes are optimized. The last intervenient, end consumer, benefits by having access to a greater availability of biomass, which according to economic principles can generate price drops.

Although it seems like a perfect world where everyone wins, application need someone that could manage it. The expected individual benefits are not so great that it is possible to take from them the share needed to manage the app. Thus, public entities could be the key in this problem, since one of the major expected gains lies in the reduction of fires, so the money saved on firefighting can be applied on this type of initiatives. In this sense, the fourth actor, local entities, arises to ensure management and support function in the platform.

3.3 Expert validation – Expert insights

As visible in section 3.2., the proposed solution seems be interesting, however as visible in section 2.2, validation is very crucial in the creation of new DT. The usability systems could be evaluated by different forms, in the present study, the methodology chosen fits inquiry techniques, where features were validated through consulting experts. This purpose will be attained resorting to an expert meeting.

During validation exercise, the experts have launched some scenarios/constrains that could be interesting to study and considered in final solution. Thus, four big contributions were detailed in this section.

- The first highlight stated is the failure to consider fuel load removers. Although this model was created to avoid the leftovers open burning, the central objective of the platform is the rural fire reduction, being important reduce fuel loads. Although the model detailed in previous section, have considered some potential monetary gains to the producer, that could be used, for example, in fuel management activities, the excess of fuel loads will continue to contribute a high fire risk rate.
- The second highlight is the possibility of missing actors in the chain, which can be a prob-

lem, and complicate the functioning of the model, since the central objective of collecting and, possibly, recovering them may not happen and make the application (model) discredited and, therefore, with little impact in societal terms.

- The third highlight note is the biomass eco-points (which consists in containers where RB can be deposited) that have been added in local towns with agroforestry activities. The objective of this measure is to give another destination to the traditional burning leftovers and could be important to reduce small productions, aggregating them in a single collection point.
- The fourth highlight relies on the lack value of leftovers, because RB sometimes has stones and irons that are undesirable to the energy conversion.
- The fifth point is that it may not be possible to recover it economically, given its low value, but many producers may be happy simply to have a destination for their leftovers.

Another proposed change was to change the term "local entity" to "Managing Entity" (ME). Thus, considering the insights proposed in the validation with experts, the model will be redesigned and considered in the new application proposal.

3.4 Output section - TO-BE information model and Platform redesign

3.4.1 TO-BE information model

The first major change follows on from the first highlight, which concerns the possible need to carry out fuel management activities. Thus, the model change lies in the possibility of having two paths to dissect the model (two intermediate events). The criterion for taking one path or the other is land abandonment, i.e. whether the area is subject to land abandonment or not. In other words, whether the area has frequent agroforestry activity (which gives rise to leftovers during agroforestry practices, such as pruning) or whether the area has no activity, having high fuel loads, that arise naturally.

Once the need for fuel management activity has been identified, the question arises as to who will carry it out, if producer (landowner) or another entity. If the activity is not carried out by the producer, it will be carried out by an intermediary (an entity specializing in these services) or by the ME, in line with the second highlight, the possible lack of actors in the chain. Ending the fuel management process, the question arises as to if the leftovers will be stay on site or not. If s/he does not leave them, a new decision arises whether to leave them at a local biomass eco-point, a reality in many Portuguese localities, as was praised by the experts (third highlight), or whether to deliver them directly to the end consumer, ending the cycle. If the entity does not collect the leftovers, they remain on site and then the model proceeds to the same point as if the model had started along the alternative path, to an area without land abandonment. Here there is a new quantity of leftovers generated that is in a producer's territory.

Here a new decision arises, if the town has eco-points, then the leftovers must be deposited in these eco-points with objective of concentrate the biomass and facilitate its subsequent phases (transportation steps). If, on the contrary, this possibility does not exist, then the producer must communicate the leftovers existence to avoid keeping leftovers. In the next phases there is a need to transport these leftovers, whether they are at eco-points or at the producer's home. There may arise three entities capable of doing, a transporter, the end consumer (when quantities can justify its collection), and ME, if none of the above provide this service. In all cases, the leftovers reach the end consumer, who can be a biomass central, a pellets industry, etc. This will not change the proposed model. Regarding the fourth highlight, there may be a need to create new mechanisms for analyzing deposits along the eco-points, which may be using more advanced technology or trying to achieve greater centralization of the eco-points, for example with its exchange for parks with windows for the provision of leftovers and where there will be competent people for this filtering. Regarding the fifth highlight, the major change could be made in terms of altering financial transactions, which may not be a necessity from the producer's point of view. Thus, this revenue could be channeled into transport and activities that are essential, further increasing the viability of the model. The Figure 3 summarizes the entire model described here.

3.4.2 The new application concept

At the process level, starting with the scenario of the fuel management activities need that will not be carried out by the producer, there is a need to call an external entity. Here, due to the duality of possibilities in which the model begins, the producer actor is no longer solely and exclusively someone who has

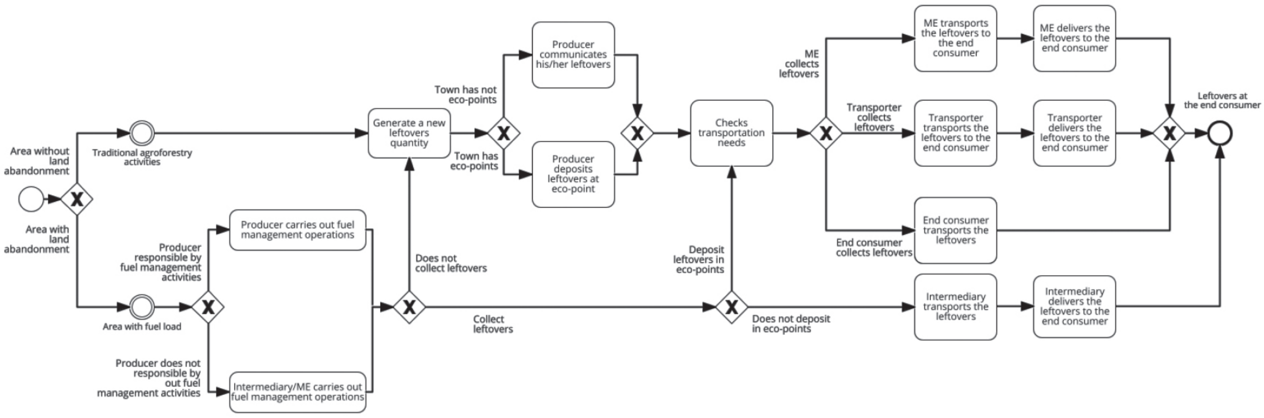

Figure 3. Summary of TO-BE model

leftovers as in the previous model but also includes any other person who has areas that need fuel management interventions. Comparing with the platform described in point 3.2.2., the intermediary is missing as an actor in the system. Regarding specific requirements of this actor, the communication of the characteristics of his/her services, as well as its ability to carry leftovers, can be highlighted. At the same time, the producer also has an increase in his/her requirements, as visualize information about the intermediary. Furthermore, it may be interesting for the system, the producer classification about the quality of the intermediary service.

Following the path of leftovers in eco-points, these must be communicated to avoid overly full eco-points or ineffective collections, and can also improve information, and consequent decision-making. Therefore, these requirements are added to the intermediary and producer actors. This communication can be done automatically if there are technologies capable of doing so, such as sensors, being possible to consider sensor as another actor in the system. However, this solution is too futuristic and is not the reality of small localities in the Portuguese context. Regarding the activity of communicating leftovers in the system (when the village does not have such eco-points), the requirement remains the same as the model presented in point 3.2.2.

After leftovers deposited (at the eco-point or at the producer's land) and communicated, the next phase follows, transportation. As this can be done in several ways, the ME and end consumer also now have the requirements previously only attributed to the transporter in the concept presented in section 3.2.2. Thus, in the end consumer was also added the requirement to communicate whether to collect the leftovers, having access to information on the collection route and which leftovers are to be collected. Some requirements also had to be modified, such as the two that refer to financial transactions, because these can or cannot occur, and those that relate to indicators, which are now broader to not make the platform's list of requirements very massive.

The last actor considered was ME, who aggregates all application support functions (such as register members, or validate pre-registration), as well as information about current region status. Besides this, ME accesses information about areas that need fuel management operations, accesses information about routes which are performed by transporter/ end consumer, have information about leftovers that do not have any transportation, having also access to collection route for them. The Table below (Table 1), summarizes the requirement list.

4. Discussion

4.1 Theoretical implications

As visible by literature, climate change [7], associated with land abandonment [10] contributes to the increasing tendency verified in burnt land areas [1]. The leftovers recovery may contribute to fire mitigation, however, RBSC is highly challenges tagged that make residual biomasses recovery unfeasible [11]. RBSC optimization has been made resorting to mathematical models [24], however, one problem of this chain relies on the lack of information, where arises the research question of the present work, and where results present a relevant contribution. Concerning the results, this study starts in a simplified model with a direct flow as a base, where leftovers produced by agroforestry activities are communicated in a platform

Table 1. Set of requirements for the new platform: comparison with the existing set

Actor	Requirement	Unchanged?	Modified?	Added?
Producer	Communicate agroforestry leftovers characteristics;		✓	
	Visualize financial transaction data;	✓		
	Communicate the need of management operations;			✓
	Visualize the intermediary characteristics for fuel management operations;			✓
	Classifies the intermediary service;			✓
	Communicate agroforestry leftovers in eco-point;			✓
Intermediary	Communicate characteristics of the service s/he provides;			✓
	Insert information on whether s/he can collect leftovers;			✓
	Communicate agroforestry leftovers in eco-point;			✓
Transporter	Visualize the collection route;	✓		
	Visualize indicators;		✓	
	Communicate the collection availability window;	✓		
	Communicate the transport type (capacity, fuel usage…);	✓		
End consumer	Insert what type of leftovers s/he accepts;	✓		
	Communicate the discharge availability window;	✓		
	Visualize the indicators;		✓	
	Insert financial transaction data;		✓	
	Visualize the collection route;			✓
	Communicate the transport type (capacity, fuel usage…);			✓
	Insert information on whether s/he can collect leftovers;			✓
ME	Visualize indicators about the region's status;	✓		
	Register new members in the platform;	✓		
	Validate pre-register made by possible users;	✓		
	Visualize information about areas that need fuel management operations;			✓
	Visualize information about routes which are performed by transporter/end consumer			✓
	Visualize the collection route;			✓
	Communicate the transport type (capacity, fuel usage…);			✓

and, after that, the transporter receives this information, collects leftovers, and delivers them in the end consumer [13]. To serve this purpose, an application concept was proposed in [14]. Although this concert has clear value for the chain, it needed validation, to try to understand if it is in line with the needs of the environment or if there is a need for redesign. This approach goes in line with one usability dimension proposed by Maqbool and Herold [31], inquiry, where requirements are defined. This point can be stated, firstly, because the study purpose was to analyze, refine, and, consequently, propose a new requirement list for a technological solution, and secondly by the methodological approach used, which could be compared to a focus group, one technique indicated by the same authors to achieve this purpose.

It was then realized that the component of fuel management activities in areas subject to abandonment should be considered and therein lies the big difference when compared to the solutions already presented [13], [14]. The result of the TO-BE model goes in line with the [12], since fuel management activities in the forest are often carried out by an external entity and, in this sense, this work aims to add digitalization to the selection processes, increasing transparency and reducing misinformation. The results have two positive impacts on the prevention of rural fires, first because can decrease the negligent attitudes toward fire, many times associated with the eradication of leftovers and, indirectly way, increase the amount of biomass availability, which can contribute to an increase in renewable energy share, acting positively against the climate change. Biomass characteristics such as seasonality or high moisture content are problems that could increase the solution value since it contemplates algorithms and aggregates information that provides greater knowledge and improve decision-making processes, which goes in line with the results of SC digitalization in other studies [28]. Regarding the circular economy, more specifically in the recovery of leftovers, in other industries, DT are an added value as it makes the chain more reactive [29]. This result goes in line with this study, as information is becoming available, it allows, for example, just a click away for an end consumer to change the state from "I do the load" to "I do not it" and the information easily reaches the ME which provides a solution, and the proposed model works again.

At sustainability level, some works, as study of Kamariotou et al. [27], argues that DT can improve these areas, which is also visible in this study, concerning to the Sustainable Development Goals (SDG), this platform could contribute to SDG3- "Good health and well-being", because acts as a fire reduction and fires are responsible for big amounts of gases and particles emissions. Concerning to the SDG7- "Affordable and Clean energy", the contribution is clear, more biomass, more share of a renewable energy. SDG8- "Decent work and economic growth" is other goal where this platform could contribute because app will provide a more transparent information about forestry operations (such as fuel management operations) that allow more transparent transactions, helping in economic growth, as well as money saved in fire combat that allow economic growth. SDG9- "Industry, Innovation and Infrastructure" is also visible in the results obtained since this field still needs technological advances. By that reason, the platform could contribute to this innovation. Advancing two goals, it is possible to find SDG11- "Sustainable Cities and Communities", which is probably the major goal accessed here, because proposed app acts as promoter of safe housing as well as enhancing better air quality, beside this, the goal states ensure a better waste management, that could be easily transposed to ensure a better leftovers management. The last two SDG addressed here are 13- "Climate action" and 15- "Life on land". The first one was already explained, the increase in renewable energy share and decrease in rural fires allow a decrease in gases emissions. The second one because fires are responsible by many deaths of living beings and habitat. These results seem closer to the results of literature [36] concerning to the sustainability, being the difference in the impact of rural fire mitigation considered in present work.

4.2 Practical implications

The results of present paper emerged in the context of Portugal, a Mediterranean country, however as the inductive character of methodological approach, it is possible to infer those results may be applied in other contexts. The problems that are in the basis of rural fires (the three conditions, climate, fuel loads and ignitions) are the same in other regions and the contribution of this model and app concept contributes in a direct way to the suppression of two problems fuel loads and ignitions and in an indirect way to the mitigation of climate changes. The literature and benchmarking actions [14] show a lack of models/tools in this sense. However, it is important to note that different contexts may have different characteristics, for example, the digital population skills or the access to the internet. Still, in the model domain, it is possible to perceive that it fosters the transition to CE, a concern visible in various countries, avoiding the exploitation of new biomasses, and diminishing the pressure on forestry resources. The usage of residual biomasses may foster the increasing of renewable energy share, which can be very valuable to the attainment of countries' decarbonization targets, emphasizing the value of proposed model and application.

5. Conclusions

The problem of rural fires is a constant in different countries, emphasizing the to develop solutions to avoid this phenomenon, and improving people's living conditions. The literature in this work allows us to conclude that climate change, combined with forest abandonment added to the need to use fire to eradicate leftovers are the main drivers of fire occurrence. The agroforestry leftover recovery appears as a solution to reduce fire risk; however, the lack of information channels makes the recovery unfeasible. This work aims to fill this gap in the literature by proposing a complete model and tool concept. Thus, this work emerged as a validation of models and concepts already presented previously, using the opinion of experts in the area. As contributions from this work, a more complete model emerges for the recovery of these leftovers, which includes not only cases of already cut leftovers that need disposal but also areas that require fuel management operations, as well as a concept for a possible platform that can respond to these needs.

As future work, follow-up in the usability study phases can be identified, and a prototype can be built for further validation (in terms of heuristics and standards), as well as validating this proposed model as a real case study, for example by carrying out case studies, to understand whether it is complete and whether it really has the intended value. These case studies may validate if the inferring that conclusions emerged in this context may be the same for different countries. Limitations of the study include the lack of case studies to validate solutions with real situations or the lack of quantitative data collection instruments to, for example, measure the strength of each suggested highlight.

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