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The use of game theory in the management of agroecosystem services

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Abstract: Agroecosystems provide a number of ecosystem services that are essential to human well-being. The valuation of these services by stakeholders offers important information that can be used to manage them more efficiently. In agroecosystems, individual stakeholder preferences can be heterogeneous and even opposing. This paper puts forward a novel analytical framework based on game theory to integrate the valuation of ecosystem services by different stakeholders into agroecosystem management. To illustrate it, the agricultural region of Los Vélez (south-eastern Spain) is used and three game modalities are applied (prisoner's dilemma, common-pool resource game and battle of the sexes). Results indicate that the use of game theory contributes to more effective conflict resolution between stakeholders with different interests and priorities, making it easier to reach consensus on optimal management strategies. This approach can guide policymakers in the design and implementation of socially accepted agroecosystem management policies.

Keywords: decision-making; ecosystem services; management strategies; stakeholders; valuation

An agroecosystem is defined as a spatially and functionally coherent unit that has been modified by people and is primarily dedicated to agricultural production (Martin-Clouaire 2018). Agroecosystems are not limited to the place where agricultural activity takes place; they interact with the surrounding ecosystems, both man-made and natural (de Groot et al. 2022). An agroecosystem comprises three interconnected subsystems: a productive subsystem, consisting of the managed cropland; a natural or semi-natural subsystem, which includes the habitats around the fields and is essential for biodiversity conservation; and a human subsystem, consisting of settlements and infrastructure, which is the decision-making unit that influences the other subsystems (Liu et al. 2022).

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Farmer-managed agricultural ecosystems provide multiple ecosystem services (ES) that play a vital role in sustaining human well-being. In addition to food production, they contribute to climate regulation, erosion control, soil conservation, landscape aesthetics and habitat maintenance (Ulrich et al. 2023). Adapting the ecosystem services framework developed by the Millennium Ecosystem Assessment process to the case of agroecosystems, four main categories can be identified: provisioning services, such as food, water, timber and fibre; regulating services, such as pollination, climate regulation, water purification and pest control; cultural services, such as recreation, tourism and artistic inspiration; and supporting services, such as soil formation and nutrient cycling (Zabala et al. 2021). The provision of these services depends on the type of agroecosystem, its management and the conditions present in the area.

The valuation of ES can provide information useful in the design of policies to promote food production and nature conservation. This valuation needs to take into account societal preferences, as these may vary according to the cultural and socio-economic context. The management of ES in an agroecosystem must consider the needs of different stakeholders (Velasco-Muñoz et al. 2022). These include farmers, hunters, livestock farmers, local communities, businesses, governments and non-governmental organisations, among others. Understanding the perceptions and preferences of the various stakeholders is crucial for effective management. Identifying what stakeholders consider valuable in the ES makes it easier to tailor management strategies to their expectations, which in turn can strengthen their support for the conservation actions implemented.

In this context, it is essential to take into account the existence of diverse actors with their own interests and objectives, at times conflicting. These differences can lead to conflict regarding the use of natural resources, the conservation of natural ecosystems and biodiversity, and the agricultural and conservation policies to be applied. It is thus important to acknowledge that stakeholder relationships are complex and at times conflicting, and to establish an analytical framework able to encompass the differences existing among stakeholders when assessing and managing agroecosystem ES.

Although research on agroecosystem services (AES) has developed considerably in recent years, very few studies have analysed stakeholder relationships and conflicts in terms of ES valuation and management. In this regard, Liu et al. (2019) suggest that one line of research that should be prioritised is the relationships among stakeholders, so as to mitigate conflicts and identify optimal decision points. According to Liu et al. (2022), one of the relatively unexplored research topics in AES that deserves further discussion is that of stakeholder interrelationships. Stokes et al. (2023) say that an under explored area of research is how stakeholders react to different types of uncertainty and how these uncertainties are dealt with in AES analyses. Satama-Bermeo et al. (2024) point to the scant attention paid to power relations and conflicts between stakeholders with respect to AES.

Given this limitation, the use game theory can help to establish an analytical framework with which to appropriately integrate AES valuation by stakeholders into management decision-making and to resolve any discrepancies that may exist. Game theory (GT) studies strategic decision-making in situations of interaction between rational agents (Myerson 1991). It is formalised in mathematical models that represent the preferences, strategies and outcomes of participants in various scenarios. The task of GT is to find optimal strategies for the behaviour of the participants in a given conflict in order to maximise their 'gains' or minimise their 'losses' (Hart 1992). Participants in the game have to choose between alternative behaviours, each of which leads to certain consequences, more or less preferable for the players. Since it is a flexible tool, it can be adapted to different contexts and applied in a variety of settings. Its usefulness lies in the fact that it allows strategic situations to be modelled, incorporating the valuations of the actors involved and offering alternative recommendations adapted to a wide range of attitudes and objectives (Osborne 2004).

GT has been used in different areas of the field of agriculture, ranging from methodological proposals to empirical applications (Cabrera García et al. 2013; Zhu et al. 2022). However, the valuation of AES is an area almost completely unexplored in relation to the application of GT. So far, only the study by Kamyab et al. (2024) has proposed that GT be used. This article evaluates the hydrological ES of agricultural practices in the Zarrinehroud river basin (Iran) using secondary information (databases and technical reports). To do so, they integrate the leader-follower GT with the conflict resolution model. To our knowledge, there are no studies using direct empirical data that explore the use of GT in agroecosystem management based on AES valuation.

To fill this gap, this paper proposes a novel analytical framework based on the use of GT to integrate stakeholder valuation of AES in the management of an agroecosystem. This approach facilitates the effective

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resolution of conflicts between stakeholders with different interests and priorities, enabling consensus on optimal management strategies to be reached. The objective of this study is thus to develop and apply a novel analytical framework based on game theory to integrate stakeholder valuations of agroecosystem services into management decision-making. Specifically, the research question addressed is: How can game-theoretic modelling improve conflict resolution and consensus-building among stakeholders with divergent interests in AES management? The feasibility and effectiveness of the proposed methodology is illustrated through its application to a real case. The agricultural region of Los Vélez (south-eastern Spain) is used because it is representative of an agroecosystem that generates multiple ES involving a wide range of stakeholders with conflicting interests.

MATERIAL AND METHODS

Study area. The case study is located in the agricultural region of Los Vélez, in south-eastern Spain. This region is characterised by a semi-arid climate, with low rainfall and long periods of drought that generate agri-environmental challenges such as water scarcity, progressive erosion and loss of biodiversity. The agroecosystem within the study area is based on a system in which five main activities coexist: rain-fed agriculture, with almonds being the main crop; traditional livestock farming, dominated by sheep; a growing service sector centred on rural, landscape and cultural tourism; hunting activity that occupies specific, delimited areas; and a nature reserve that covers one fifth of its territory.

This agroecosystem provides a wide range of ecosystem services and is threatened by pressure from different activities, leading to conflicts between stakeholders regarding its management. The agro-environmental and socio-economic characteristics, plus the mix of different and interdependent activities, make the area of Los Vélez an ideal place to examine the aforementioned questions.

Survey and data collection. The use of primary data for AES valuation is considered a viable option for providing information to decision-makers (Richardson et al. 2015). For this paper, a participatory methodology including expert knowledge and questionnaires was chosen. The first phase consisted of selecting and defining the ES to be assessed and the stakeholders to be surveyed. For this task we arranged for the participation of a group of experts involved in the functioning and management of this area's agroecosystem. A total of 12 experts were interviewed in February and March 2024. The interviews were conducted in person and focused on a list of possible ES to be assessed and stakeholders to be consulted.

Using the information obtained in this phase, a questionnaire was designed to collect primary information on the valuation of the AES in the area. The questionnaire included a total of 15 ES that belonged to one of three categories, following the classification of Zabala et al. (2021): provisioning, regulating and cultural services. Specifically, five ES were assessed for each of the categories and five key stakeholder groups were considered (Table 1).

The data collection process ensured that all respondents belonged to one the five key stakeholder groups, to guarantee they were familiar with the different ES they were asked to assess. A snowball sampling technique was used for their selection, whereby each respondent recommended other potential participants from among their acquaintances. A total of 176 valid surveys, evenly distributed across the stakeholder typology, were conducted. The surveys were conducted in person in April and May 2024.

Game theory. GT is a formal framework that can be used to analyse decision-making in situations involving strategic interaction. GT models make it possible to study the implications of rationality, self-interest and equilibrium, both in market interactions modelled as games (such as where there are small numbers, hidden information, hidden actions or incomplete contracts) and in non-market interactions (such as between a regulator and a firm, a boss and a worker etc.) (Gibbons 1997). A game involves the following elements (Osborne 2004): players, rules, strategy, information, outcomes, equilibrium and period.

A wide array of modalities can be applied in GT depending on the number of players, the number of strategies, the nature of the interaction between players, the nature of the win, the number of moves, the state of information, etc. In this paper a static, two-player, finite, non-cooperative model was chosen. Three strategic situations (prisoner's dilemma, common-pool resource game and battle of the sexes) were deemed the most appropriate for this research because they allow for the modelling of discrete individual choices between the different AES. One AES from each of the three major blocks (provisioning, regulation and cultural services) is considered in each game.

In the characterisation of a game it is important to describe its form (structure) in a concise way that is neither very difficult to understand nor so easy that it ignores important elements of the strategic situation

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Table 1. Valuation of ecosystem services by stakeholder

	Agriculture	Livestock farming	Hunting	Tourism	Government	Total
Provisioning	79.0	81.1	78.3	80.2	80.0	79.7
Almond	80.6	72.1	70.0	65.6	75.2	72.7
Pasture	71.0	82.4	71.7	78.8	80.0	76.8
Bee-keeping	98.1	95.4	93.3	92.4	89.0	93.6
Esparto	64.5	72.7	70.0	73.3	69.7	70.1
Fauna	80.6	83.1	86.7	91.1	86.2	85.5
Regulating	89.5	88.3	82.3	89.5	90.7	88.1
Air	86.3	84.6	83.3	86.8	89.7	86.1
Climate	91.2	89.1	76.7	89.2	92.8	87.8
Habitat	87.4	87.6	76.7	85.2	88.7	85.1
Aquifer	88.3	90.2	86.7	90.4	91.3	89.4
Soil	94.2	90.1	88.3	96.0	91.3	92.0
Cultural	83.1	83.6	84.7	87.1	86.4	85.0
Aesthetic	79.4	79.8	83.3	77.6	85.2	81.1
Education	89.7	86.2	83.3	91.6	89.3	88.0
Heritage	92.9	91.5	88.3	82.4	85.2	88.1
Recreational	75.5	78.2	83.3	94.0	85.6	83.3
Tourism	78.1	82.4	85.0	90.0	86.7	84.4
Total	83.8	84.4	81.8	85.6	85.7	84.3

Source: Authors' own elaboration

(Barati et al. 2021). Among the great variety of forms that can be used to describe a game (Myerson 1991), this research opts for the 'strategic form' because of its effectiveness due to the direct and simple extraction of its results. Additionally, as the strategic situations develop, the utility functions of each stakeholder must be defined. In this research it is assumed that satisfaction with the ES is directly related to the value of the payoff received by each player. Furthermore, the set of actions that constitute the strategies of each player must be specified. If the payoff functions and the actions of the players are known, the payoff matrix can be constructed and the equilibria of the game can be analysed.

RESULTS

Valuation of agroecosystem services

Table 1 shows the results of the valuation of the fifteen ES considered, which have been grouped into three large blocks: provisioning, regulating and cultural. The degree of satisfaction that each of the AES offered to the stakeholders was measured using a five-point Likert scale, 1 being the lowest score and 5 the highest. All values were homogenised to 100 (according to the maximum possible score). Also, thanks to the information extracted, the total aggregate valuation of all the AES could be obtained. In aggregate, the three blocks are highly valued, although regulating services are the most highly valued, above cultural and provisioning services. By type of stakeholder, livestock farmers value provisioning services the most, the government values regulating services and the tourism sector values cultural services. In contrast, hunters are the ones that value provisioning and regulating services the least, and it is farmers that value cultural services the least. In turn, for each of the 15 AES analysed, there are important differences in the valuations of each of the stakeholders, which may lead to conflicts when prioritising certain management measures over others.

Application of game theory

Using the valuations of the AES given by stakeholders, different hypothetical scenarios were explored. Specifically, three strategic situations were considered: prisoner's dilemma, common-pool resource game and battle of the sexes. The analysis was performed using static games that, thanks to their simplicity and clarity, can be represented in matrix form without losing mathematical rigour. The three proposed games reflect the complexity of the discrepancy situations arising between stakeholders and allow the situations to be

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analysed from different perspectives. The prisoner's dilemma captures the tension between players in situations that require cooperation, the common-pool resource game presents a structure in which individual pursuit of maximum benefit leads to overexploitation of a shared resource, and the battle of the sexes models situations in which players have different preferences but wish to coordinate their actions to reach a mutually acceptable equilibrium. By combining these three games a more complete picture is obtained of the dynamics underlying conflicts derived from differences in stakeholder preferences.

The ES selected within each block was not chosen solely on the basis of the magnitude of the differences in valuation by stakeholders, but rather, and primarily, on the strategic characteristics of the observed interaction. For the provisioning block, ES pasture was chosen because it exemplifies a situation of interdependence with potential incentives for non-cooperative behaviour, typical of the structure of the prisoner's dilemma. In the regulating block, ES soil was selected not because it has the largest discrepancy in valuation, but because of its intrinsic characteristics as a common pool, limited resource subject to potential overexploitation by multiple actors. These conditions make it particularly suitable for analysis through the common-pool resource game structure. In the culture block, ES heritage and recreation was chosen because of the asymmetry in stakeholder preferences and the existence of a common interest in obtaining government investment. This coordination challenge, where each actor prefers a different equilibrium but both seek joint action, reflects the core structure of the battle of the sexes game.

Prisoner's dilemma. In this game, two defendants accused of a crime are separately offered the option of either informing on the player or not doing so: if one informs and the other does not, the maximum penalty will be imposed and the informer will go free; if both inform, an intermediate penalty will be imposed on both; if both remain silent, both will be given the minimum penalty. The dilemma is that the best individual action resulting from non-cooperation (informing on the other) does not lead to the best collective outcome resulting from cooperation (silence).

In the case study, within the provisioning block, the ES pasture is valued very differently by agriculture (AG) and livestock farming (LF) (71 and 82.4, respectively). If both stakeholders could cooperate and opt for sustainable practices that ensure long-term availability of pasture, such as rotational grazing, the use of fencing to control pasture access and the restoration of degraded areas etc., then the AG and LF sectors would obtain a value for the use of pasture that we consider here of 71 and 82.4, respectively. This cooperation would favour the maintenance of productive relations, preserving biodiversity and ecosystem health, sustaining pasture quality, which may lead to beneficial agreements in later periods. However, if stakeholders prioritise short-term incentives and decide to try to extract a higher individual benefit, e.g. by reducing the costs of pasture management and assuming a lower level of commitment to eco-sustainable practices, the resulting situation may harm both actors in the short and long term.

Table 2. Prisoner's dilemma on ES pasture

		Livestock Farming (LF)	
		Yes	No
Agriculture (AG)	Yes	71. 82.4	65. 85
	No	74. 75	68. 78

ES – ecosystem services
Source: Authors' own elaboration

This strategic situation has characteristics of the prisoner's dilemma. As an example, the available strategies defined for each stakeholder are 'sustainable grazing management' (Yes) and 'no sustainable grazing management' (No). Once the assumptions in place are known, the payoff matrix can be constructed and the behaviour of the stakeholders analysed. Table 2 shows the payoff matrix for this game. In this exemplification exercise, we assume that the payoff each player receives if they both choose the 'yes' option corresponds to their valuation of grazing, i.e. 71 for agriculture and 82.4 for livestock farming. The rest of the payoffs in the matrix reflect the tension between the benefits of cooperating in the long run and the incentives to pursue profits in the short run. In this situation, the best individual strategy for each stakeholder, regardless of what the other stakeholder does, is always not to cooperate. Thus (No, No), with payoffs for AG and LF of 68 and 78 respectively, constitutes the only equilibrium in the game since neither player has incentives to unilaterally choose another action given the action chosen by the other. This equilibrium leads to a suboptimal collective outcome since the payoffs if both choose 'yes' are higher for both. In the event that one cooperates and the other does not: the one who cooperates is the one who extracts the maximum possible utility in the short run, to the detriment of the other player.

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This analysis suggests that, like in the classic prisoner's dilemma, the impossibility of establishing binding agreements favours short-term incentives that reduce cooperation and can lead to suboptimal results for the agroecosystem as a whole. Solutions to this problem may include, among other tools, communication mechanisms between stakeholders, incentives for cooperation, clear rules and sanctions for non-cooperation, and the establishment of guidelines and means to monitor compliance with agreements reached (in addition to sanctions).

Common-pool resource game. This game is specifically about the management of shared natural resources, an intrinsic characteristic of agroecosystems. The mathematical model represents a strategic situation in which a set of actors makes use at the same time of a common resource which, by definition, is limited. As a common resource, it belongs to everyone and anyone can make use of it. In this mathematical model, each actor's profit will depend on the amount that actor extracts, and also on the amount extracted by the rest of the actors involved. The most frequent result in this approach is known as 'the tragedy of the commons': each player thinks solely of his or her individual interest and dismisses the collective interest, so he or she extracts more resources than what is considered sustainable, and the generalisation of this behaviour leads to the extinction of the common resource (Ostrom 1990).

In the case study, within the regulating block, the ES soil is valued differently by agriculture (AG) and hunting (HU) (94.2 and 88.3, respectively). Both stakeholders value this ES from their own perspective. From the AG side, it is valued that fertile soils lead to higher quality crops, are more resistant to climatic variations, require less external inputs, and contribute more to biodiversity conservation, among others. From the HU side, the availability of food for fauna, suitable habitat for species, and better regulation of biogeochemical cycles, among others, are valued.

As the soil of this agroecosystem is a common and limited resource used by the different stakeholders, it is appropriate to model it through the common-pool resource game. Taking into consideration the assigned values, a hypothetical payoff matrix can be developed, in which each stakeholder has only two actions available: soil conservation or soil overexploitation (Table 3). In this game, we assume that the payoff of each stakeholder, when both choose to conserve soil, is their ES soil valuation. The payoff for the stakeholder increases by 50% when that stakeholder overexploits the resource while the other conserves it, and decreases by 75% when that stakeholder conserves while the other overexploits. Finally, when both stakeholders overexploit the resource, their payoffs correspond to 50% of their valuation. The structure of the game coincides with that of the prisoner's dilemma. In this case, the only possible (suboptimal) equilibrium is that both players overexploit the 'soil' resource, obtaining payoffs of 47.1 for agriculture and 44.2 for hunting. This result is lower than what they would obtain if they cooperated in sustainable conservation (94.2 and 88.3, respectively), so an intervention that facilitates cooperation would benefit both parties, as in the previous analysis.

Table 3. Common-pool resource game on ES soil

		Hunting (HU)	
		Conservation	Overexploitation
Agriculture (AG)	Conservation	94.2. 88.3	23.6. 132.5
	Overexploitation	141.3. 22.1	47.1. 44.2

ES – ecosystem services
Source: Authors' own elaboration

Battle of the sexes. In this classic GT scenario, a couple wants to enjoy an event together: she wants to go to the theatre and he wants to go to a concert. They both want to be together rather than go individually to either of their preferred activities. However, each must decide on an activity without knowing the activity chosen by the other. In this scenario there are two equilibrium outcomes in which the couple is at either the theatre or the concert. These outcomes constitute equilibria since, given the activity chosen by the other, neither has an incentive to switch activities. However, it is difficult to predict the outcome of the game.

The 'battle of the sexes' is an example of a more general class of games known as coordination games. In this type of game, communication can be essential as it allows players to 'coordinate' in mutually preferred equilibria. However, unlike other coordination games, in the battle of the sexes the equilibria in which both attend the theatre or both attend the concert cannot be ranked using the Pareto criterion, since each player strictly prefers one equilibrium over the other (it is not possible to improve the satisfaction of one without reducing the satisfaction of the other). Unlike the prisoner's dilemma, where the cooperative outcome does not constitute a static game equilibrium, in the game discussed here the players have incentives to coordinate

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Table 4. Battle of the sexes on heritage vs. recreational

		Tourism (TU)	
		HP	RP
Hunting (HU)	PH	88.3. 82.4	0. 0
	PR	0. 0	83.3. 94.0

HP: Heritage Promotion; RP: Recrational Promotion
Source: Authors' own elaboration

with each other, but have different ideas on how to do so. It is a case in which there can be multiple equilibria that represent successful coordination, the difficulty lies in the players choosing the best one.

In the case study, within the cultural block (CUL), the ES heritage is rated relatively highly by the hunting sector (88.3) but receives a relatively low rating by the tourism sector (82.4); meanwhile, the ES recreational is rated relatively highly by the tourism sector (94.0) yet receives a relatively low rating by the hunting sector (83.3). It is easy to imagine a situation in which the government is willing to invest in the promotion of one of these ES (heritage or recreational) but not both. However, the government will only make the investment if both sectors ask for investment in the same ES. If the sectors request investment in different ES, the government will not make the investment. Here the strategies available for each sector are to request investment in heritage promotion (HP) or to request investment in recreational promotion (RP). The strategic situation is depicted in Table 4. In this illustrative example, we assume that when the sectors request investment for the promotion of different services, the government does not invest and each sector gets a zero payoff. Thus, the equilibria correspond to the two strategies (HP, HP) and (RP, RP).

DISCUSSION

Game theory has been used in areas as different as water resource management (Yan and Cao 2024), environmental pollution and mitigation strategies (Feng at al. 2023); in ecosystem conservation (Khiavi et al. 2024); and in cooperation between different stakeholders for sustainable forest management (Zandebasiri et al. 2022; Sprinz et al. 2024). However, to date, there has been no specific research in the area of AES.

This study uses an original approach to the analysis of ES management in agroecosystems, integrating analytical frameworks from game theory as a means to model strategic interactions between actors with divergent interests. Unlike more traditional approaches based on optimisation models or static cost-benefit analysis, this study recognises the relational, dynamic and strategic nature of environmental decision-making, in line with the recommendations by Hanley et al. (2019) on the need to incorporate microeconomic tools that capture interactive behaviours. The novelty of this study lies in its use of a well-known methodology (game theory) for a different or new purpose, the management of agroecosystem ES.

The results obtained align with the research priorities identified by Liu et al. (2019, 2022), who highlight the critical role of stakeholder interactions and conflict resolution in AES management. Unlike previous studies, which mainly conceptualise the need for improved stakeholder engagement (Stokes et al. 2023; Satama-Bermeo et al. 2024), the present article operationalises these interactions through formalised game-theoretic models. This provides a practical analytical tool to predict strategic behaviours and to design conflict mitigation mechanisms. Additionally, by applying direct empirical valuation data rather than secondary sources, as done for instance in Kamyab et al. (2024), this study offers a more context-sensitive and stakeholder-informed basis for agroecosystem management.

This study contributes to the existing literature by adapting three game theory models to the empirical study of ES in an agroecosystem, thus giving the analysis greater explanatory power regarding the coordination, cooperation, and alignment constraints faced by the actors involved. The use of the prisoner's dilemma to analyse the management of the ES Pasture illustrates how the absence of cooperation in contexts of shared benefits can lead to socially inefficient equilibria. This observation has been widely documented by Axelrod (1984), who highlights how cooperation is difficult to sustain in the absence of repetition or reputation mechanisms. In this regard, the present study reaffirms the validity of such models, but adds an empirical dimension by linking them to specific stakeholder valuations of ES, thus providing quantitative analysis applied to a real context.

The analysis of the ES soil using the common-pool resource game expands on Hardin's (1968) foundational ideas regarding the 'tragedy of the commons' and also considers the contributions of Ostrom (1990), who emphasised the ability of communities to develop effective self-management institutions. Through the construction of a payment matrix that incorporates cross-incentives and loss of value in the event

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Table 5. Practical implications of applying GT in the agroecosystem of Los Vélez

Type of ES	Theoretical game applied	Practical implications identified
Provisioning (ES pasture)	prisoner's dilemma	promote sustainable pasture management agreements implement economic incentive programmes for good practices establish local round tables for consultation and ongoing dialogue
Regulating (ES soil)	common-pool resource game	create specific local regulations for land use and conservation promote certification of good agroecological practices establish controlled use and/or rotation zones
Cultural (ES heritage and recreational)	battle of the sexes	facilitate mediation processes between tourism and hunting sectors develop integrated sustainable tourism development plans design unified communication strategies to attract public investment

ES – ecosystem services; GT – game theory

Source: Authors' own elaboration

of overexploitation, this study offers an accessible representation of mechanisms that can lead to the deterioration of a common resource, while pointing to potential alternatives for institutional intervention, such as external regulation or voluntary coordination.

The application of the battle of the sexes model to ES cultural (heritage and recreational) represents a significant conceptual innovation. While the literature tends to focus on collective action models with homogeneous preferences or distributional conflicts, this study recognises that even when there is a willingness to collaborate, differences in the prioritisation of objectives can hinder joint action. As Fudenberg and Tirole (1991) point out, coordination games with asymmetric preferences have multiple possible equilibria and require additional mechanisms to resolve strategic uncertainty. The present analysis illustrates how this problem can emerge even in the design of environmental public policies, where government investment is contingent on the strategic alignment of the actors involved.

Practical applications

The results of this analysis have important practical implications for the management of ES in the Los Vélez agroecosystem, which is characterised by its environmental value and a socio-economic structure based on agriculture, livestock farming, hunting and tourism.

The prisoner's dilemma game model applied to the management of ES pasture reveals the latent risk of adopting non-cooperative strategies, even when cooperation would be more beneficial for both actors. In practice, this suggests the need to develop formal cooperation mechanisms between agricultural and livestock sectors. Some examples of such mechanisms are shown in Table 5.

The common-pool resource game model applied to the management of ES soil suggests a tendency towards overexploitation if there are no regulatory mechanisms or explicit agreements in place. For the agroecosystem of Los Vélez, where soils are a critical resource for multiple sectors, these findings support practices such as those shown in Table 5.

The battle of the sexes game model applied to the management of ES cultural (heritage vs recreational) highlights the importance of achieving strategic alignment so as to attract public investment intended to enhance the value of natural and cultural heritage. In practice, this leads to a number of actions, like those listed in Table 5.

Beyond the specific sectoral actions appearing in Table 5, the study suggests the need to strengthen local social capital and promote participatory governance mechanisms that enable the strategic barriers limiting cooperation to be overcome. As Ostrom (1998) points out, these mechanisms may include the clear definition of usage rights, the creation of consensual access rules, community monitoring, and the application of sanctions proportional to infringements.

The practical application of this study's findings could contribute significantly to the ecological sustainability and socio-economic resilience of the agroecosystem of Los Vélez, aligning the management of ES with local development and long-term environmental conservation needs.

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CONCLUSION

This study highlights the need for an integrated analytical framework that captures the different interests and preferences of stakeholders in agroecosystem management. To this end, a novel analytical framework based on the application of GT was developed. To illustrate it, the agricultural region of Los Vélez is used and three game modalities are applied (prisoner's dilemma, common-pool resource game and battle of the sexes). The results indicate that the use of GT can facilitate the effective resolution of conflicts between stakeholders with different interests and priorities, allowing consensus to be reached on optimal management strategies. Also, the diversity of the situations that emerged in the three games applied to the local realities of this agroecosystem could contribute to a better shared understanding by stakeholders of the challenges and possibilities in agroecosystem management and even point to solutions in line with their expectations.

One of the main advantages of the proposed methodology is its ability to accommodate the interests and preferences of different stakeholders. Furthermore, it offers an integrative approach to conflict resolution, promoting a more effective decision-making process. Although here the proposed methodology has been applied in a specific context, it is versatile enough to be applicable to other agroecosystems as well. In terms of possible implications for management, the application of GT to AES valuation helps identify different management options by which to optimise management practice. By incorporating stakeholder preferences for the AES, this proposal can guide policymakers in the design and implementation of socially supported agroecosystem management policies.

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