Evaluación integrada de prácticas y diseño de políticas agrarias orientadas a la multifuncionalidad y la sostenibilidad: Aplicación a sistemas agrarios olivareros de Andalucía y lecheros de los Países Bajos

Mª Carmen Carmona Torres

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TESIS DOCTORAL

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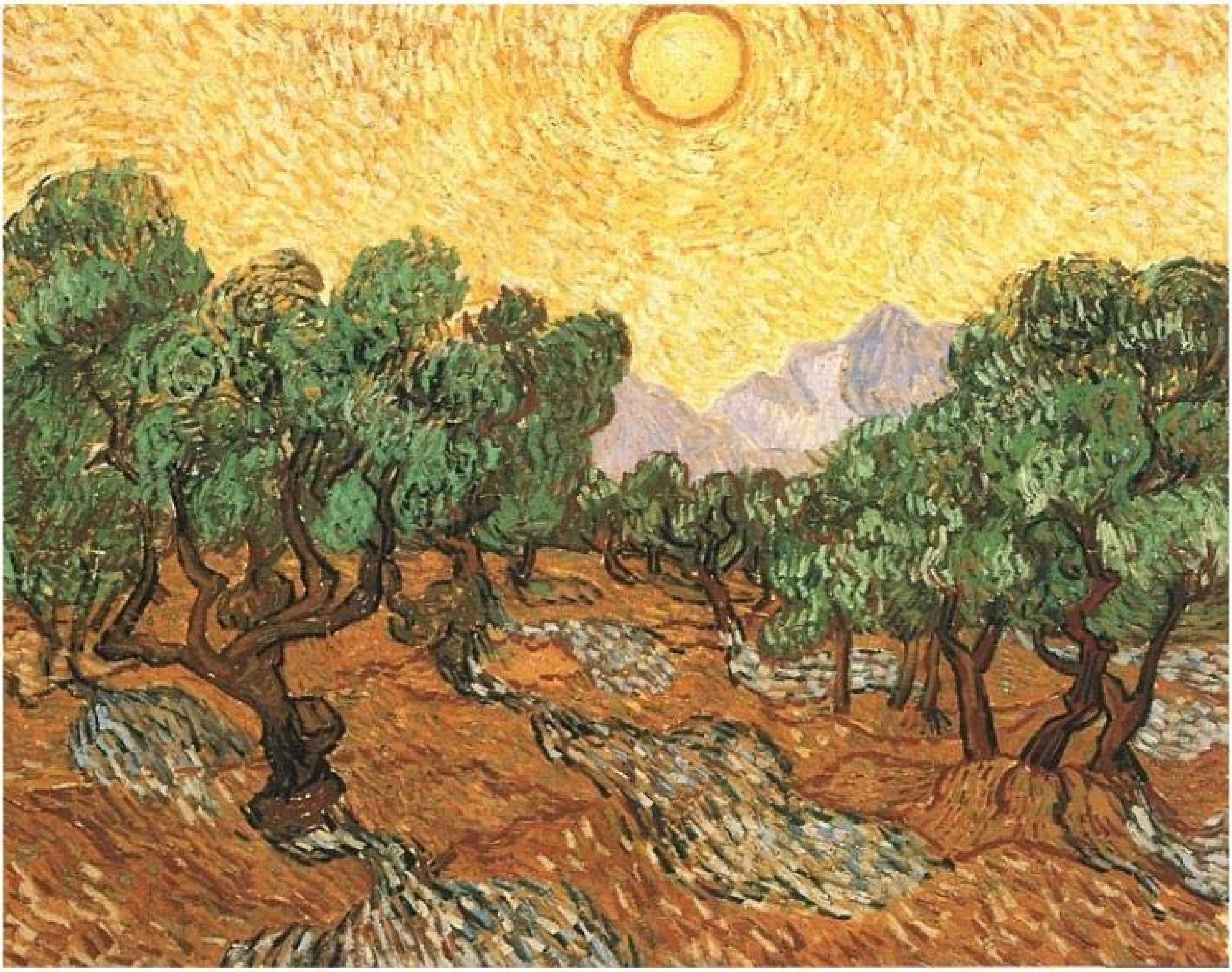

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Memoria que la Licenciada Mª Carmen Carmona Torres presenta para aspirar al Grado de Doctor por la Universidad de Granada

Esta memoria ha sido realizada bajo la dirección de:

Dr. Carlos Parra López

Lda. Mª Carmen Carmona Torres
Aspirante al Grado de Doctor

Granada, julio de 2015

Dr. Carlos Parra López, Investigador Titular del Instituto de Investigación y Formación Agraria y Pesquera (IFAPA) de la Junta de Andalucía

CERTIFICA

Que los trabajos de investigación desarrollados en la Memoria de Tesis Doctoral: "Evaluación integrada de prácticas y diseño de políticas agrarias orientadas a la multifuncionalidad y la sostenibilidad: Aplicación a sistemas agrarios olivareros de Andalucía y lecheros de los Países Bajos", **son aptos para ser presentados por la Lda. Mª Carmen Carmona Torres ante el Tribunal que en su día se designe, para aspirar al Grado de Doctor por la Universidad de Granada.**

Y para que así conste, en cumplimiento de las disposiciones vigentes, extiendo el presente certificado a 15 de julio de 2015

Dr. Carlos Parra López

El doctorando, Mª Carmen Carmona Torres, y el director de la tesis, Carlos Parra López, Garantizamos, al firmar esta tesis doctoral, que el trabajo ha sido realizado por el doctorando bajo la dirección de los directores de la tesis y hasta donde nuestro conocimiento alcanza, en la realización del trabajo, se han respetado los derechos de otros autores a ser citados, cuando se han utilizado sus resultados o publicaciones.

Granada, 15 de julio de 2015

Director/es de la Tesis | Doctorando

Fdo.: Carlos Parra López | Fdo.: Mª Carmen Carmona Torres

Durante el tiempo de realización de esta Tesis Doctoral he disfrutado de un Contrato Predoctoral dentro del Proyecto de Investigación "Multifuncionalidad agraria y políticas públicas: integración de la demanda social en el diseño y evaluación de políticas agroambientales en el olivar andaluz (MULTIOLI)" (PAIDI P07-SEJ-03121), de la Consejería de Innovación, Ciencia y Empresa de la Junta de Andalucía.

Este trabajo estuvo financiado por los proyectos MULTIOLI (PAIDI P07-SEJ-03121) de la Junta de Andalucía y MULTIPREF (RTA2006-00055) y ECOINNOLI (RTA2008-00024-00-00) del Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA).

La investigación presentada en esta Tesis Doctoral se ha realizado en el Departamento de Economía y Sociología Agrarias del Instituto de Investigación y Formación Agraria y Pesquera (IFAPA) de la Junta de Andalucía y en el Biological Farming Systems Group de la Universidad de Wageningen, Países Bajos.

A mi familia, que me ha enseñado a soñar,

y a Carlos, mi compañero de camino,

junto a quién los sueños se hacen realidad.

No basta con adquirir sabiduría, es preciso además saber usarla.

Cicerón (107-44 a.C.)

La práctica debería ser fruto de la reflexión, no al contrario.

Hermann Hesse (1877-1962)

AGRADECIMIENTOS

La presente Tesis Doctoral, como todas, ha supuesto una gran inversión de esfuerzo, dedicación e ilusión. Y también como todas ha contraído gozosas deudas de agradecimiento y gratitud, profundas y sinceras, que intentaré manifestar en este apartado personal dedicado a dar las gracias a algunas de las personas que han contribuido, ya sea profesional o emocionalmente, en esta magnífica empresa.

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Y justamente por cuanto el final de un trabajo no se entiende sin sus principios, aunque estos se dilaten en el tiempo, en mi largo camino ha sido primordial la intervención de Javier Calatrava Requena, que me abrió las puertas al apasionante mundo de la investigación, me proporcionó los medios, me guio y acompañó tanto tiempo en los inicios de esta singladura. Igualmente siento un gran cariño y gratitud hacia mis compañeros y amigos del IFAPA de Granada, así como hacia los profesores de Universidad con que he tenido la inmensa fortuna de contar en Granada, Córdoba y Zaragoza. Entre todos me brindasteis los conocimientos y los ánimos para adentrarme en esta nueva disciplina que se abría ante mí

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ÍNDICE

RESUMEN

Resumen

En la presente Tesis Doctoral se desarrolla un marco metodológico integrado con el fin de evaluar el comportamiento multifuncional de los sistemas agrarios y definir prácticas agrarias más sostenibles económica, ambiental y socialmente, y diseñar políticas agrarias que favorezcan la adopción de las técnicas agrarias óptimas desde el punto de vista de su sostenibilidad global. Para ello se combinan diferentes metodologías de valoración económica, modelización integrada, el análisis de las partes interesadas y la evaluación multicriterio. El marco metodológico se desarrollará y aplicará para dos casos de estudio, el olivar de Andalucía y explotaciones lecheras intensivas del norte de los Países Bajos, sistemas de elevada significación económica, social y ambiental en sus respectivas regiones. La hipótesis subyacente en la Tesis, y que ha sido contrastada, es que en la actualidad no se están implementando por parte de los agricultores, en ambos sistemas agrarios, las técnicas agrarias más sostenibles globalmente debido a que no se están considerando adecuadamente en el diseño de políticas agrarias y agroambientales públicas los beneficios y costes públicos y privados de todas las partes interesadas y las funciones de mercado y no-mercado de los sistemas agrarios a nivel de explotación y/o paisaje. Así, los objetivos últimos de la investigación son: 1) priorizar las funciones de no-mercado, o no comerciales, de los dos sistemas agrarios analizados según las demandas sociales a la agricultura; 2) identificar técnicas de cultivo y paquetes tecnológicos óptimos de acuerdo con su comportamiento multifuncional y sostenibilidad global a nivel de explotación y/o paisaje y definir los cambios necesarios en las técnicas agrarias actuales para alcanzar mayores niveles de sostenibilidad; y 3) definir mecanismos políticos eficientes para promover un cambio efectivo en las técnicas implementadas por los agricultores con el fin de alcanzar la adopción de las técnicas o paquetes tecnológicos de mayor sostenibilidad global en los dos sistemas agrarios objeto de estudio.

En el **artículo 1** se desarrolla y aplica un modelo integrado de evaluación de la multifuncionalidad a nivel de explotación para el caso de la olivicultura andaluza. El modelo se basa teóricamente en el método de análisis de decisión multicriterio Proceso Analítico de Red (ANP), alimentado por el conocimiento de 27 expertos, una encuesta a 400 olivareros de Andalucía y revisión bibliográfica. El objetivo es evaluar el comportamiento multifuncional de la olivicultura a nivel de explotación, incluyendo sus funciones económicas (costes de producción, rendimiento y calidad del producto), sociales (desarrollo rural y empleo, identidad cultural y paisaje) y ambientales (erosión, fertilidad del suelo, contaminación de las aguas, biodiversidad) en función de las técnicas agrícolas aplicadas referidas a la plantación, manejo del suelo, riego, fertilización, tratamientos fitosanitarios, recolección y poda. Los resultados indican que, en general, los oleicultores están aplicando alternativas técnicas que son óptimas para la obtención de un producto de alta calidad, pero están descuidando hasta cierto

punto los impactos sociales y, sobre todo, los ambientales. A pesar de la evolución positiva en la última década, todavía hay mucho margen de mejora. Los grupos de prácticas más sensibles que deberían mejorar son el manejo del suelo, el riego y la fertilización. Los resultados también ponen de manifiesto que un mejor resultado económico para los agricultores no es incompatible con los objetivos sociales, tales como el desarrollo rural y el empleo, y con la protección del medio ambiente del suelo, el agua y la biodiversidad. Finalmente, los resultados indican el mayor rendimiento multifuncional de algunos paquetes agrícolas alternativos como la producción integrada y la intensiva. En el **artículo 2** se desarrolla un marco metodológico integrado para el diseño de políticas públicas que promocionen técnicas agrícolas más sostenibles globalmente según los beneficios netos privados/públicos asociadas a las mismas. El trabajo combina dos modelos multicriterio ANP sobre las múltiples funciones de la olivicultura, uno de ellos desarrollado en el artículo anterior, con un análisis económico y un marco de los Beneficios Públicos/Privados Netos (BPPN) para el diseño de políticas. Se consideran los beneficios y costes de todas las partes interesadas: productores, consumidores de aceite de oliva, administraciones públicas y la sociedad en general. Una encuesta a 409 ciudadanos permite definir las preferencias de la sociedad andaluza hacia la agricultura. Los resultados muestran que técnicas como la cobertura del suelo, la fertilización orgánica, el análisis de suelo o de la hoja antes de la fertilización, el análisis de la calidad del agua de riego, la fertirrigación, la frecuencia de riego siguiendo el consejo de expertos y la baja intensidad de la poda deben ser promovidos por políticas que favorezcan una mayor sostenibilidad. El mecanismo de política revelado como la más eficiente es la extensión agraria. Los contratos territoriales y los programas agroambientales también pueden resultar útiles. Los resultados también demuestran que la maximización de la sostenibilidad no está reñida con la mejora de los beneficios netos privados de los oleicultores. En el **artículo 3** se pretende integrar las múltiples demandas sociales hacia la agricultura en la evaluación la multifuncionalidad de la actividad agraria a nivel de paisaje, en el caso de la ganadería intensiva lechera del norte de los Países Bajos, en concreto de la región de Northern Friesian Woodlands. Las funciones de no-mercado analizadas son la calidad del paisaje (variación en el número de especies de plantas en los pastizales e irregularidad en el patrón de los setos), el valor natural (diversidad de especies en el pasto y setos) y la salud ambiental (baja pérdida de nitrógeno). Las alternativas de paisajes vienen definidas por variables estructurales de las explotaciones como el tamaño y la fertilidad del suelo y por variables de manejo como los regímenes de fertilización y siega de los pastos y la presencia o ausencia de setos alrededor de las parcelas. Las demandas de la sociedad neerlandesa se obtienen del Eurobarómetro y las relaciones entre estas demandas y las funciones de no-mercado mediante entrevistas a 10 expertos usando una combinación de las metodologías QFD y ANP. El modelo de optimización multiobjetivo Landscape IMAGES se utiliza para generar y evaluar alternativas de paisajes y revelar trade-offs entre las funciones del mercado y de no-mercado. Los resultados indican que la mejora del paisaje actual hacia el óptimo social implicaría cambios en la gestión de los pastos que resultaría en un mayor margen bruto para los agricultores y una mayor calidad del paisaje, que se podrían relajar ligeramente las restricciones ambientales actuales, y que se podía llegar a niveles más bajos de subvenciones en los programas agroambientales. En el **artículo 4** se propone un marco metodológico integrado que es una ampliación de la metodología desarrollada en el artículo anterior, que permite trasladar los beneficios netos de mercado y no-mercado en beneficios privados (de mercado para los ganaderos) y públicos (de mercado y no-mercado para el resto de agentes). El objetivo es explorar y seleccionar agro-paisajes potenciales sostenibles en función de los beneficios privados y públicos asociados a alternativas de uso del suelo. Finalmente se definen mecanismos de políticas públicas eficientes para la mejora de beneficio social neto de los agro-paisajes. Los resultados indican que la extensión agraria es el mecanismo de política más eficiente para promover el cambio a la alternativa de paisaje socialmente óptima. En el **artículo 5** se aborda el problema de la escala espacial en la evaluación de la sostenibilidad de los sistemas agrarios y cómo la colaboración entre agricultores puede resultar en una mayor sostenibilidad de la actividad agraria sin menoscabar el beneficio privado de los agricultores. Se propone para el caso de la ganadería intensiva lechera de los Países Bajos un mecanismo institucional de compensación financiera entre los agricultores integrantes de un paisaje, basado en el criterio de Kaldor-Hicks y la mejora de Pareto y, que permita determinar cómo el apoyo público definido a nivel de paisaje se puede distribuir de manera equitativa a nivel de explotaciones y posibilite una mejora óptima de Pareto. La evaluación del comportamiento multifuncional de los sistemas ganaderos se basa en los modelos desarrollados en los dos artículos anteriores. Los resultados muestran que los beneficios de los diferentes ganaderos difieren considerablemente debido a diferencias biofísicas, ecológicas y geográficas de sus explotaciones. El mecanismo propuesto pretende contribuir a una mayor equidad entre los agricultores y se debe basar en la confianza mutua, la comunicación y la capacidad de control y sanción, y la descentralización de la toma de decisiones hacia un nivel más local. La implementación del mecanismo propuesto podría ser a través instituciones informales, como el acuerdo verbal entre los agricultores, o los formales, como a través de las formas contractuales o con medidas específicas dentro de los programas agroambientales.

INTRODUCCIÓN GENERAL

Introducción general

1. Antecedentes y alcance

1.1. Demanda social por una agricultura multifuncional y sostenible

La toma de conciencia social sobre las consecuencias negativas del desarrollo industrial a toda costa, en general, y de la agricultura química, en particular, se inicia tímidamente en los países más desarrollados a finales del siglo XIX y comienzos del XX (Parra-López, 2003). No obstante, no es hasta la década de los 70, con el movimiento ecológico, cuando surge en los países más desarrollados una corriente de pensamiento contraria al desarrollo técnico indiscriminado y al crecimiento económico a cualquier precio, debido, entre otras causas, a que se empiezan a sentir las consecuencias negativas que se derivan de los mismos (p.ej. primeros desastres ecológicos) y a que se toma conciencia de que los recursos naturales son agotables (p.ej. crisis petrolífera de 1973). Hasta esa fecha, las políticas de desarrollo y los círculos académicos se referían a la 'eficiencia' de las actuaciones económicas, es decir, se limitaban a un análisis unicriterio meramente económico-financiero de las mismas. Sin embargo, a partir de los 70 el concepto de equidad comienza a utilizarse, referido a la consideración de todos los beneficiados y, como novedad, de todos los afectados en cualquier actividad económica. En la década de los 80 se empieza a hablar de sostenibilidad, concepto que hace referencia a la consideración del medio ambiente y de las generaciones futuras en la planificación económica (Parra-López, 2003). En el terreno de la política agraria de la Unión Europea, a partir de la reforma de la PAC de 1992 se empieza a hablar del papel multifuncional de la agricultura. Frente al tradicional rol meramente productivista de la misma, se comienza a reconocer explícitamente su importancia en relación a la conservación del medio ambiente, la generación de rentas paralelas al sector agrario (turismo agrario, rural, etc.), su efecto como catalizador en la generación de empleo en el medio rural, etc. Además, se reconoce que la sociedad demanda nuevas funciones a la agricultura, en particular, y al medio rural, en general, relacionadas con la preservación del medio ambiente y la mejora de la calidad de vida en las zonas rurales (Sayadi et al., 2009; Sayadi y Parra-López, 2009). De esta forma, a la hora de evaluar el valor o comportamiento de un sistema agrario no se trataría de valorar exclusivamente un criterio económico-financiero sino que se deduce que esta evaluación debería ser multicriterio, en relación directa con el papel multifuncional de la agricultura, y multiactor, en relación a la consideración de los beneficios y costes de las diferentes partes interesadas, tanto los agentes productivos como la sociedad en general.

1.2. Evaluación de la multifuncionalidad y sostenibilidad de la agricultura

La ciencia no ha permanecido ajena a esta paulatina consideración de las cuestiones relativas al medio ambiente y a las cuestiones sociales, como nuevos criterios a tener en cuenta en la planificación pública de políticas agrarias y agroambientales. Así, desde inicios del siglo XX se han ido desarrollando nuevas propuestas teóricas y metodológicas tendentes a la inclusión de los temas medioambientales y sociales en la resolución de los problemas relacionados con el desarrollo económico, básicamente encaminadas a la valoración de activos ambientales y del impacto de actuaciones humanas sobre el medio ambiente. Así, han ido surgiendo bajo el paradigma de la Teoría Económica Neoclásica, y más concretamente de la Teoría Económica del Bienestar, el cuerpo doctrinal de lo que hoy se denomina Economía Ambiental. En paralelo, han ido surgiendo diversas aproximaciones teóricas, que se apartan en mayor o menor grado de la teoría económica neoclásica ortodoxa, y que tienen en común su rechazo de la valoración monetaria de los bienes ambientales y el reconocimiento de que las actividades económicas tienen lugar dentro del medio ambiente, del cual dependen y al que, a su vez, afectan. La conservación del medio ambiente es considerada, por tanto como esencial, para el mantenimiento en el tiempo de las todas las actividades humanas. Este conjunto de aproximaciones, más que un cuerpo axiomático perfectamente definido y mayoritariamente aceptado, consiste en un conjunto de técnicas y metodologías de clara vocación práctica. Es lo que se conoce como Economía Ecológica, la cual abarca la economía convencional neoclásica de los recursos y el medio ambiente y va más allá, al incorporar la evaluación física de los impactos ambientales de la economía humana (Martínez-Alier, 1999).

En el campo concreto de la evaluación de la multifuncionalidad y sostenibilidad de la agricultura, se han venido utilizando fundamentalmente técnicas de modelización bioeconómica a nivel de explotación (Janssen y van Ittersum, 2007; Rossing et al., 2007; Zander et al., 2008), basadas en su mayoría en la programación u optimización matemática (Janssen y van Ittersum, 2007). La mayoría de los trabajos no llevan a cabo una evaluación realmente integrada debido a la no incorporación de funciones sociales, una escasa representación de temas bióticos y paisajísticos dentro de las funciones ambientales y económicas, una débil aproximación interdisciplinaria de análisis y una escasa implicación de las partes interesadas (Rossing et al., 2007). No obstante, algunos pocos estudios han adoptado un enfoque más holístico de forma explícita, como los de Gómez-Limón y Arriaza-Balmón (2011); Parra-López et al. (2007, 2008); Villanueva et al. (2014), que analizan una amplia gama de funciones del olivar. Sin embargo, estos precedentes carecen de una perspectiva sistémica, ya que las múltiples funciones de la olivicultura no se vinculan explícitamente con las técnicas agrarias específicas aplicadas por los agricultores, sino a tipos de agricultura, como la convencional, ecológica, integrada, tradicional, semi-intensiva e intensiva. En resumen, según nuestro conocimiento no hay información disponible desde una perspectiva integrada. La planificación de políticas de uso del territorio para una agricultura multifuncional y sostenible puede beneficiarse de este enfoque integrado (Mattison y Norris, 2005). Este enfoque integrado es el que se pretende aplicar en la presente Tesis Doctoral. Para ello se combinarán diferentes metodologías de valoración económica, modelización integrada, el análisis de las partes interesadas y la evaluación multicriterio, tal y como se sugiere en la literatura sobre gestión y políticas hacia la sostenibilidad y la optimización del bienestar (Turner et al., 2000), en consonancia con los postulados de la Teoría de la Decisión Multicriterio y de la Economía Ecológica (Hernández y Cardells, 1999).

1.3. Diseño de políticas agrarias hacia la sostenibilidad

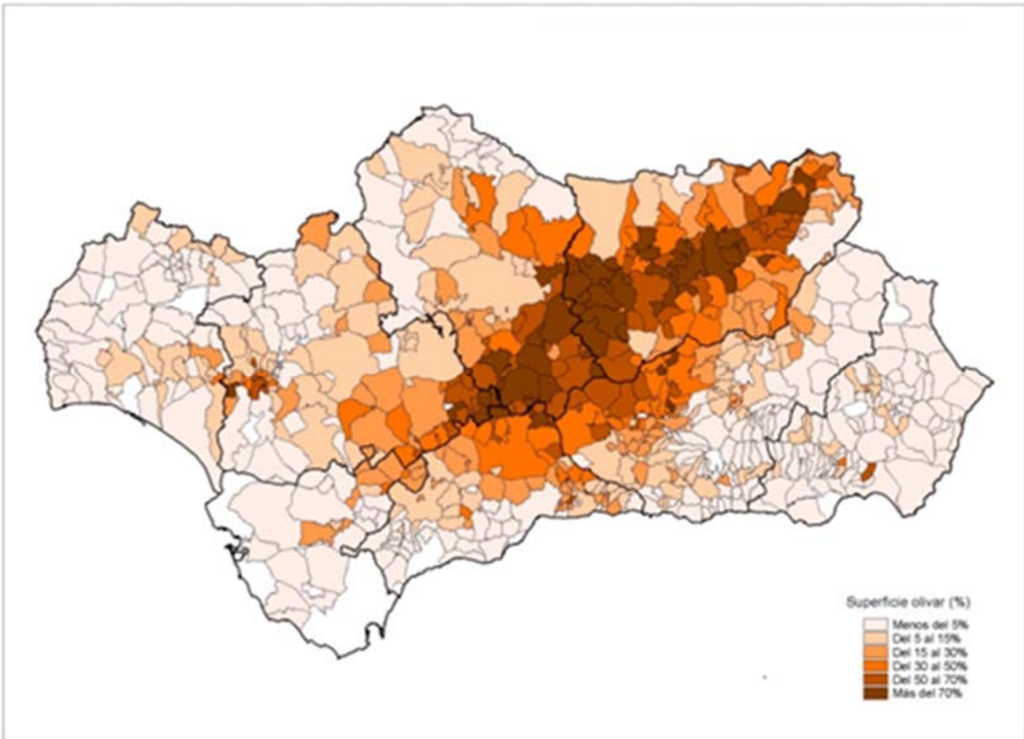
El reconocimiento del carácter multifuncional de la agricultura obliga a considerar junto a los objetivos convencionales de la Política Agraria Común (PAC) de producción competitiva y adecuadamente remunerada para el agricultor, nuevos objetivos ligados al resto de funciones proporcionadas por la agricultura. Los sucesivos reglamentos de la PAC, en sus aspectos agroambientales, han planteado un sistema de pagos por hectárea vinculados al lucro cesante o al coste adicional que supone el cambio de prácticas, más un determinado porcentaje adicional en concepto de incentivo (García y Barreiro-Hurle, 2004; Sumpsi et al., 1997). Sin embargo, este formato de apoyo no es el único disponible y, posiblemente, tampoco sea el óptimo para la conservación de la naturaleza (aspecto ambiental de la multifuncionalidad) en terrenos agrarios (Latacz-Lohmann y Van der Hamsvoort, 1998). En particular, el sistema de pagos únicos puede ser ineficiente en el contexto de información asimétrica y provisión de bienes públicos. La investigación en sistemas alternativos de intervención pública forma parte de la agenda de trabajo que surge en torno al concepto de multifuncionalidad (Batie, 2003). Así, dentro de una tendencia a largo plazo de reducción de ayudas y mayores restricciones presupuestarias parece relevante investigar alternativas para potenciar el papel multifuncional de la agricultura, contrastar los instrumentos políticos existentes con las preferencias públicas y diseñar alternativas políticas óptimas que permitan recuperar la legitimidad y el apoyo social a dichas políticas así como aumentar la eficiencia de la producción conjunta de los sistemas agrarios. Se trata en definitiva de lograr una perspectiva política a largo plazo a favor de una agricultura sostenible desde el punto de vista económico, social y ambiental. En el caso concreto del olivar, la Ley 5/2011, de 6 de octubre, del Olivar de Andalucía, y el Plan Director del Olivar, aprobado por el Decreto 103/2015, de 10 de marzo, establecen como prioridades para el olivar andaluz, entre otras, la mejora de la productividad de las explotaciones; la biodiversidad y la calidad paisajística de los olivares; la sostenibilidad ambiental y a la lucha contra el cambio climático, adaptando, en su caso, las técnicas de cultivo; y la elaboración de un código de buenas prácticas de gestión de las explotaciones.

En la presente Tesis Doctoral, se pretende diseñar y proponer instrumentos de política agraria y agroambiental alternativos que permitan asegurar la provisión de estos elementos multifuncionales a un nivel socialmente óptimo para el caso de los sistemas agrarios olivareros de Andalucía y lecheros de los Países Bajos. Este enfoque permitirá definir las técnicas agrarias óptimas desde el punto de vista de su sostenibilidad global así como el conjunto de bienes y servicios que proporcionan y, con ello, cuantificar la pérdida/mejora real de bienestar que supone la desaparición/fomento de las distintas funciones asociadas a determinados cambios en las técnicas agrarias adoptadas. Sólo así se pueden diseñar instrumentos óptimos para que (1) la sociedad conozca mejor y valore, en su caso, más adecuadamente los elementos multifuncionales de los sistemas agrarios y (2) las políticas se adapten e integren mejor a las preferencias públicas en su diseño. En definitiva, se pretende lograr unas decisiones colectivas más eficientes que maximicen el bienestar social y que permitan una gestión sostenible y multifuncional de los sistemas agrarios, así como una mejora de la gestión empresarial que incremente la competitividad de los agentes productores.

1.4. Casos de estudio: El olivar de Andalucía y la ganadería lechera del norte de los Países Bajos

Los marcos metodológicos propuestos se aplicarán a dos casos de estudio muy diferentes: el olivar de Andalucía y explotaciones lecheras intensivas en los Países Bajos. En ambos sistemas, la definición de políticas agrarias orientadas a una mayor sostenibilidad de los mismos es del máximo interés dada su gran relevancia a nivel económico, social y ambiental en sus respectivas zonas. En efecto, el cultivo del olivo constituye una importante actividad económica en los países mediterráneos, especialmente en España, que representó el 25,4% de la superficie de olivar mundial y el 33,4% de la producción en el período 2005-10 (FAO, 2012; MAGRAMA, 2013; MARM, 2010). Andalucía es la región olivarera más importante del mundo. Representa el 61,3% de la superficie y el 82,2% de la producción olivarera de España en el período 2007-2010 (CAP, 2013). El cultivo del olivo desempeña un papel socioeconómico importante en la región, proporcionando el 27,7 % de la producción hortofrutícola andaluz en el año 2010 (CAP, 2012), y generando alrededor de un tercio del empleo agrícola, del cual el 47.1% es familiar (CAP, 2009). Además, el cultivo del olivo presenta un alto potencial de impacto en el medio ambiente en la región debido a su amplia presencia territorial (Figura 1), ya que abarca el 31,94 % de la superficie agrícola de Andalucía (MARM, 2010). La mayor parte se cultiva de manera tradicional extensiva aunque una superficie cada vez mayor, alrededor del 17%, se cultiva más intensivamente con un uso masivo de insumos productivos (Hinojosa-Rodríguez et al., 2014). Por otra parte, una superficie cada vez mayor está dedicado a los métodos alternativos de agricultura, tales como Producción Integrada, adoptado por un 16% de los olivicultores (Hinojosa-Rodríguez et al., 2014), y la Agricultura Ecológica, adoptada por aproximadamente un 3% (CAP, 2010a, b). La explotación olivarera modal en Andalucía tiene las siguientes características estructurales (Hinojosa-Rodríguez et al., 2014): Área total, 1.5 ha; tipo de cultivo, tradicional; rendimiento, 4000-6000 kg de aceitunas/ha; edad de la plantación, 10-50 años; mano de obra, familiar y empleados temporales; destino del producto, aceite de oliva; pendiente del terreno, baja; sin cultivos intercalares; sin manejo del ganado; principal cliente, almazaras cooperativas de primer grado; ubicación principal de clientes, Andalucía.

Figura 1. Importancia del olivar por municipios en Andalucía (% sup. olivar/SAU)

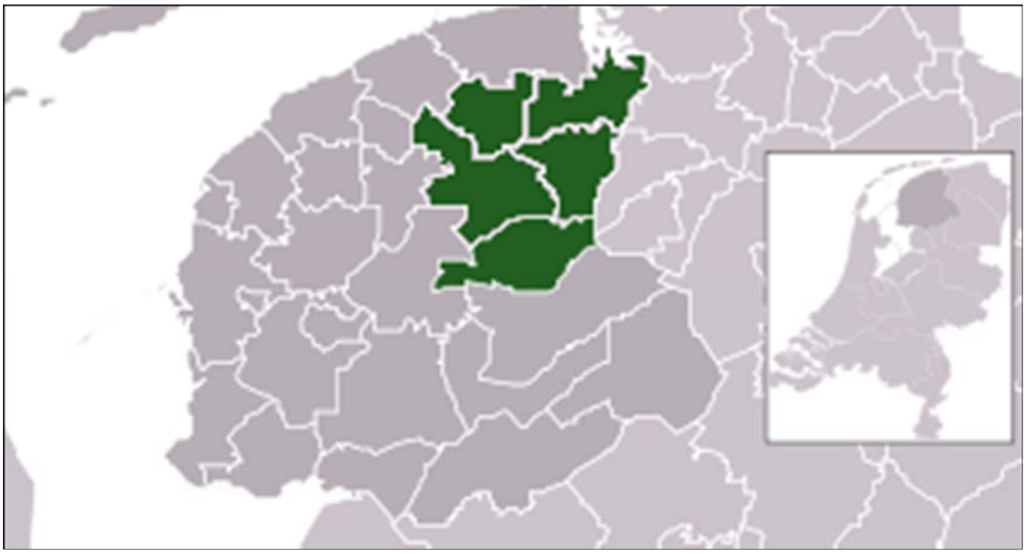


Fuente: CAP (2002)

Por otro lado se analizará un paisaje agrícola manejado de forma intensiva en Northern Friesian Woodlands, una región del norte de los Países Bajos, dedicado fundamentalmente al ganado lechero (Figura 2). El sector del vacuno de leche en los Países Bajos representa el 1,2% de la economía total, ocupa el 28% de la superficie total y el 63% de la superficie agrícola de este país; el número de explotaciones dedicadas a la producción de vacuno de leche ha disminuido de 29.500 en 2010 a 18.660 en 2013; esas granjas contaban con 1.553.000 animales que produjeron 12.207.300 toneladas de leche en 2013; el tamaño medio de las explotaciones, por el contrario, ha aumentado de 51 animales en

2000 a 83 en 2013; el rendimiento medio por vaca también se ha incrementado, desde 7.397 litros en 2000 hasta 8.000 en 2013; existen 21 industrias transformadoras de leche de vaca, 51 plantas de producción, de las que 30 son propiedad de las distintas cooperativas que se dedican a esta actividad, y 300 distribuidores mayoristas (Agronews_Castilla_y_León, 2014). La región de Northern Friesian Woodlands se caracteriza por paisajes de pequeña escala en suelos predominantemente arenosos con la ganadería lechera como actividad predominante. En algunas explotaciones se utiliza una proporción limitada de hasta el 5% de la superficie para la producción de forraje de maíz, mientras que el resto de la zona está ocupada por pastos permanentes, pastados y segados mecánicamente según rotaciones. Las explotaciones, con un tamaño medio de 2 hectáreas, están a menudo rodeadas de setos y estanques. Las características biofísicas de las explotaciones y las demandas sociales y regulaciones parar preservar el paisaje han limitado las posibilidades de dedicarse a la agricultura a mayor escala. Por otra parte, la región ofrece múltiples oportunidades para proporcionar servicios no productivos, que si fuesen remunerados contribuirían a una mayor sostenibilidad de la agricultura en la zona (Berentsen et al., 2007). En la década de los 90, los agricultores se enfrentaron a estrictas regulaciones para reducir las emisiones de amoníaco y nitrato al medio ambiente. Como respuesta, surgieron las Cooperativas Ambientales, que desde entonces desarrollan actividades para alcanzar los objetivos de las políticas pero con medidas específicas adaptadas a sus condiciones locales y aceptables para los agricultores. Además, los agricultores se comprometen a mantener el paisaje histórico, que es la base de una fuerte identidad local de sus habitantes (Renting y Van Der Ploeg, 2001).

Figura 2. Localización de Northern Friesian Woodland (Noardlike Fryske Walden)



Fuente: Elaboración propia a partir de imagen de Wikipedia: "Map - NL - Municipality code 0059 (2009)" by Michiel1972 (talk) 21:38, 24 January 2009 (UTC) - own work , using CBS data. Licensed under CC BY-SA 3.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Map_-_NL_-_Municipality_code_0059_(2009).svg#/media/File:Map_-_NL_-_Municipality_code_0059_(2009).svg

La elección de dos sistemas agrarios tan diferentes permitirá obtener conclusiones sobre la validez del marco metodológico integrado propuesto para diferentes sistemas productivos. Además, los resultados permitirán definir actuaciones comunes a nivel de la planificación de políticas públicas para la multifuncionalidad y la sostenibilidad con vocación suprarregional y suprasectorial.

1.5. Hipótesis a contrastar

La hipótesis de partida que se pretende contrastar en la presente Tesis Doctoral supone que en la actualidad no se están implementando por parte de los agricultores, tanto olivareros de Andalucía como lecheros del norte de los Países Bajos, las técnicas agrarias más sostenibles globalmente, es decir, económica, social y ambientalmente, debido a que no se están considerando adecuadamente en el diseño de políticas agrarias y agro-ambientales públicas los beneficios y costes de todas las partes interesadas, que comprenden no sólo a los actores que intercambian bienes de mercado (en este caso, aceite de oliva y productos lácteos) sino a la sociedad en general cuyas demandas a la agricultura van más allá de la mera producción de alimentos incluyendo otras muchas funciones de no-mercado como las ambientales, territoriales y socioculturales. La adopción de técnicas agrarias o de paquetes tecnológicos (conjunto de técnicas agrarias) óptimos socialmente permitiría alcanzar un nivel de sostenibilidad mayor que el actual para los sistemas agrarios analizados, maximizando así tanto el beneficio empresarial de los agricultores como el bienestar de la sociedad en general. Para alcanzar mayores niveles de sostenibilidad de los sistemas agrarios sería necesario promover/disuadir la difusión de las prácticas más sostenibles/insostenibles mediante la definición de políticas públicas agrarias y agro-ambientales eficientes.

2. Objetivos de la Tesis

El objetivo de la investigación realizada en la presente Tesis Doctoral es doble. El primer objetivo es de naturaleza teórica y consiste en desarrollar un marco metodológico integrado con el fin de evaluar el comportamiento multifuncional (económico, ambiental y social) de los sistemas agrarios en función de las prácticas agrarias implementadas, y diseñar políticas agrarias que favorezcan la adopción de las técnicas agrarias óptimas desde el punto de vista de su sostenibilidad global. El marco metodológico se desarrollará e ilustrará íntegramente para dos casos de estudio, el olivar de Andalucía y explotaciones lecheras intensivas en los Países Bajos. Este objetivo se descompone en los siguientes subobjetivos:

- Modelizar agro-ecológicamente las relaciones entre prácticas y técnicas agrarias y sus impactos multifuncionales en las dimensiones económica, ambiental y social a nivel de explotación y/o paisaje. Para ello se utilizarán la metodología multicriterio ANP (Analytic Network Process), en el caso del olivar de Andalucía, y el modelo LANDSCAPE Images, en el caso de las explotaciones lecheras de Los Países Bajos.
- Definir una metodología para cuantificar los costes y beneficios públicos y privados para todas las partes interesadas, tanto a nivel de explotación como de paisaje, asociados a las diferentes prácticas y técnicas y evaluar su sostenibilidad global. Para ello se combinará el análisis económico clásico de los bienes y servicios de mercado con la valoración no monetaria de los bienes y servicios de no-mercado o externalidades por parte de la sociedad en general mediante ANP, en el caso del olivar, y ANP combinado con la metodología QFD (Quality Function Deployment), en el caso de las explotaciones lecheras.
- Establecer un marco metodológico para diseñar políticas agrarias eficientes en términos de costes tendentes a potenciar la adopción de prácticas globalmente más sostenibles y evitar las más insostenibles. La consideración conjunta de los beneficios netos públicos y privados asociados a un cambio de técnicas agrarias permitirá determinar los mecanismos políticos más eficientes para propiciar dicho cambio si conlleva una mayor sostenibilidad de los sistemas agrarios. Para ello se usará el marco BPPN (Beneficios Públicos/Privados Netos). En el caso de las explotaciones lecheras de los Países Bajos se propondrá adicionalmente un mecanismo institucional de compensación financiera entre agricultores para abordar el problema de la escala espacial de las externalidades generadas por los sistemas agrarios.

El segundo objetivo de la Tesis es de naturaleza práctica y consiste en aplicar el marco metodológico propuesto a los dos casos de estudio, el olivar de Andalucía y explotaciones lecheras intensivas en los Países Bajos, con el fin de definir medidas y políticas concretas que propicien un cambio efectivo de las técnicas agrarias aplicadas hacia mayores niveles de sostenibilidad global. Este objetivo se descompone en los siguientes subobjetivos:

- Priorizar las funciones de no-mercado, o no comerciales, de los dos sistemas agrarios analizados según las demandas sociales a la agricultura.
- Identificar técnicas de cultivo y paquetes tecnológicos óptimos de acuerdo con su comportamiento multifuncional y sostenibilidad global a nivel de explotación y/o paisaje y definir los cambios necesarios en las técnicas agrarias para alcanzar mayores niveles de sostenibilidad.
- Definir mecanismos políticos eficientes para promover un cambio efectivo en las técnicas implementadas por los agricultores con el fin de alcanzar la adopción de las técnicas o

paquetes tecnológicos de mayor sostenibilidad global en los dos sistemas agrarios objeto de estudio.

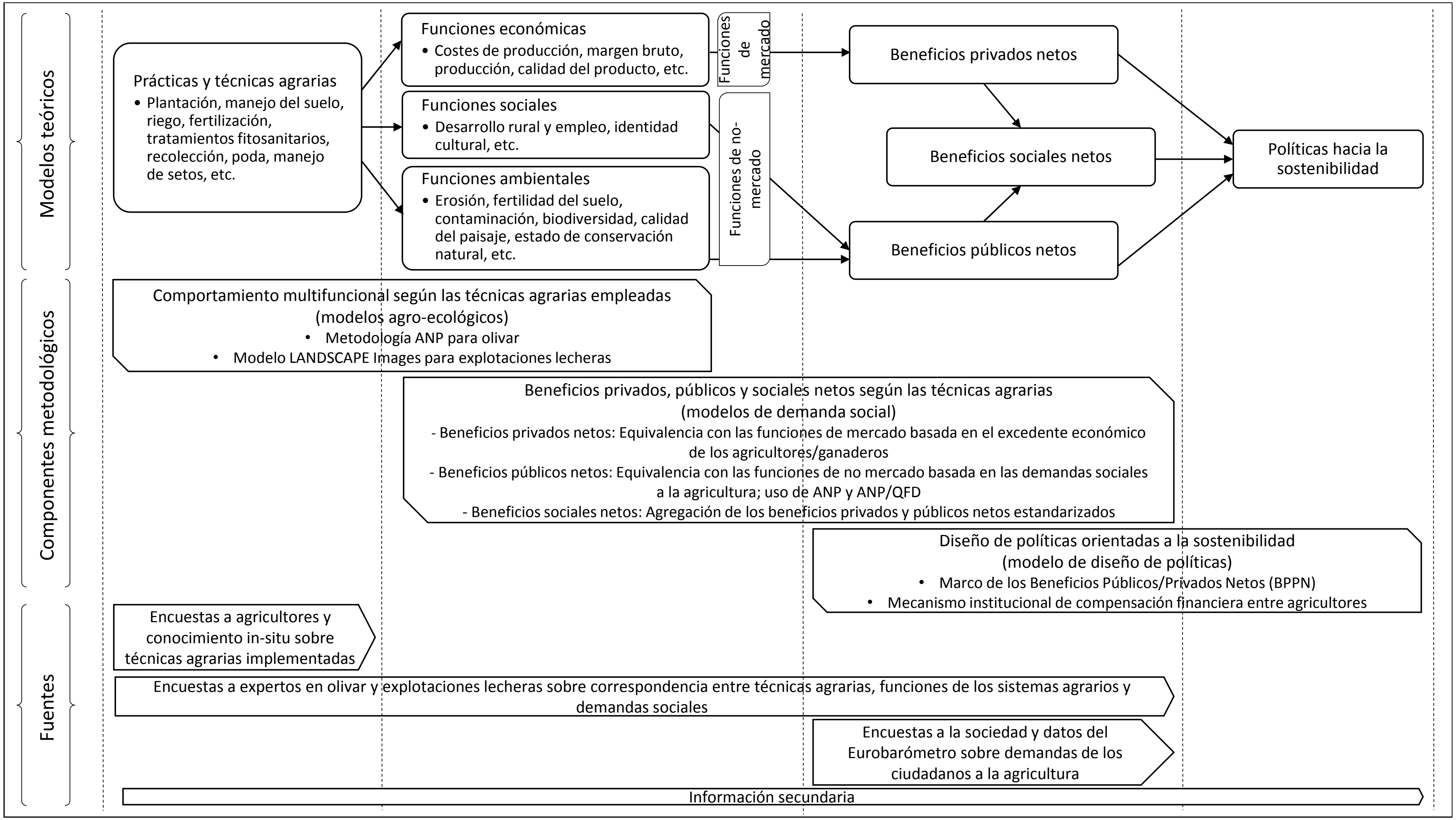
3. Metodología general de la investigación

En la Figura 3 se representa de modo sintético una visión general del marco metodológico que se ha desarrollado y aplicado a los dos casos de estudio. Se pueden apreciar los tres componentes metodológicos de que consta (que se corresponden con los tres subobjetivos del primer objetivo de la Tesis) así como los diferentes modelos teóricos que tratan de representar y las fuentes de información en que están basados.

Para conseguir los objetivos planteados se han seguido las siguientes fases:

- Fase I. Recogida, revisión y análisis de información secundaria: Consiste en la búsqueda, selección y análisis crítico de información secundaria procedente de diversas fuentes bibliográficas. Se ha pretendido actualizar el conocimiento que pudiera ayudar a la ejecución de la investigación planteada bien por su temática o por los enfoques metodológicos empleados.
- Fase II. Análisis funcional, sistémico e integrado de los sistemas agrarios objeto de estudio: Se han caracterizado los sistemas olivareros de Andalucía y lecheros de Los Países Bajos, desde una perspectiva sistémica y holística, analizando la incidencia de la adopción de unas técnicas agrarias en las múltiples funciones (económicas, sociales y ambientales) de dichos sistemas. Para ello, se han utilizado básicamente la metodología ANP y el modelo LANDSCAPE Images.
- Fase III. Valoración económica, social y ambiental: Consiste en asignar un valor económico o de utilidad social a las funciones de los sistemas agrarios analizados considerando tanto el valor de mercado de los bienes intercambiados (aceite de oliva y leche) como las preferencias sociales por las funciones de no-mercado de dichos sistemas agrarios (menor erosión, fertilidad del suelo, calidad de las aguas, biodiversidad, valor natural, calidad del paisaje, desarrollo rural y empleo, etc.). Los beneficios sociales netos se han utilizado para determinar el grado de sostenibilidad de las diferentes combinaciones de técnicas agrarias. Como se ha indicado, se han tenido en cuenta funciones de mercado y no-mercado, así como públicas y privadas. Se ha utilizado una aproximación neoclásica basada en el excedente de los agentes económicos implicados para las funciones de mercado, y la metodología ANP, en el caso del olivar, y ANP combinada con QFD, en el caso de la ganadería, para las funciones de no-mercado.

Figura 3. Marco metodológico integrado propuesto



- Fase IV. Diseño de políticas y estrategias orientadas a la sostenibilidad global: En esta fase se han analizado las políticas y mecanismos más eficientes para tratar de difundir la adopción de aquellas técnicas y paquetes tecnológicos identificados en la fase anterior como de mayor sostenibilidad. Se ha utilizado el marco BPPN. En el caso de las explotaciones lecheras del norte de los Países Bajos se ha diseñado adicionalmente un mecanismo institucional de compensación financiera entre agricultores para conseguir la adopción conjunta de sistemas agrarios más sostenibles a nivel de paisaje.

En las diferentes fases se han utilizado diferentes fuentes de información tanto secundaria, básicamente en base a revisiones bibliográficas, como primaria, tal y como se detalla a continuación:

- Encuestas a agricultores: Se ha entrevistado con cuestionarios estructurados a 400 agricultores de las principales regiones olivareras de Andalucía (Jaén, Córdoba y Granada). Con estas encuestas se han identificado las técnicas implementadas para las prácticas agrarias más relevantes por los olivareros. Previamente, para definir las prácticas más relevantes se ha usado información de fuentes secundarias. En el caso de la ganadería las técnicas aplicadas por los ganaderos fueron definidas según el conocimiento *in-situ* de la región.
- Encuestas a expertos en los sistemas agrarios analizados: Se han entrevistado cara a cara a dos grupos de expertos, en concreto 27 expertos en olivar y 10 en ganadería lechera, con el fin de terminar su opinión relativa a dos bloques de preguntas:
  - Correspondencia entre prácticas implementadas y funciones de los sistemas agrarios: Se ha definido y cuantificado la incidencia de las diferentes técnicas implementadas por los agentes productores en las funciones económicas, ambientales y sociales los sistemas agrarios.
  - Correspondencia entre funciones de los sistemas agrarios y las preferencias sociales: El fin es tratar de establecer en qué medida las diferentes demandas de la sociedad (preferencias sociales) pueden ser satisfechas por las diferentes funciones económicas, ambientales y sociales de los dos sistemas agrarios. Esto ha permitido integrar las preferencias sociales en el diseño de políticas públicas para la consecución de unos sistemas agrarios más sostenibles.
- Encuestas de preferencias sociales por la multifuncionalidad de la agricultura: Se ha realizado una encuesta *ad-hoc* a la población en el caso de la agricultura andaluza, con 409 ciudadanos entrevistados, y se ha utilizado la información secundaria proporcionada por el Eurobarómetro sobre las demandas de los ciudadanos neerlandeses a la agricultura basada en una amplia encuesta a nivel nacional. Con estas encuestas se pretendía conocer cuáles son las prioridades de la sociedad respecto al papel multifuncional de la agricultura, en general, y

con ello definir las funciones de no-mercado prioritarias según estas preferencias. Los criterios evaluados por los ciudadanos en ambas encuestas son cuestiones que les afectan directamente y que pueden ser fácilmente evaluados por ellos (p.ej. asegurar unos ingresos adecuados y estables a los agricultores, asegurar que los productos agrarios son sanos y seguros, la conservación del medio ambiente, etc.). Posteriormente estas preferencias se han hecho corresponder con las diferentes funciones de los sistemas agrarios estudiados, como se verá a continuación en el desarrollo de las metodologías, las cuales pueden referirse a cuestiones más técnicas o científicas (p.ej.: erosión, biodiversidad, calidad del paisaje, etc.).

En la investigación se han utilizado diferentes metodologías, que a continuación se detallan brevemente, cuya combinación constituye la base teórica del marco metodológico integrado que se ha desarrollado:

- Metodología ANP (Analytic Network Process – Proceso Analítico de Redes): Es una técnica de toma de decisiones multicriterio discreta, que junto a AHP (Analytic Hierarchy Process – Proceso Analítico Jerárquico) que es su origen (Saaty, 1980; Saaty, 2001), se está empezando a utilizar en problemas de evaluación y selección ambiental. La resolución de dichos problemas consiste, básicamente, en la priorización u ordenación de un conjunto de alternativas en base a su grado de satisfacción de una serie de objetivos o criterios. AHP representa los objetivos estructurados en forma de jerarquía, dependiendo los inferiores de los superiores, mientras que ANP es una generalización de AHP, estructurando los objetivos en forma de red, en la cual todos los objetivos pueden estar interrelacionados con el resto. ANP y AHP han sido utilizadas previamente por los participantes en la presente Tesis para evaluar comparativamente los impactos económicos, ambientales, técnicos y socioculturales del olivar convencional, ecológico e integrado (Parra-López et al., 2007, 2008). Si bien AHP/ANP han sido usadas en la planificación de políticas energéticas (p.ej. Hamalainen y Seppalainen (1986)) y han sido utilizadas en el contexto de la Evaluación de Impacto Ambiental (Ramanathan, 2001), según nuestro conocimiento no existen precedentes de su aplicación en España en el ámbito de la planificación de políticas, en general, y agroalimentarias, en particular, lo cual es un valor añadido de la presente Tesis Doctoral. En concreto, ANP se ha utilizado en la Tesis para definir las relaciones entre prácticas y técnicas agrarias y sus impactos multifuncionales a nivel de explotación, y entre sus impactos multifuncionales y las demandas sociales, en el caso del olivar de Andalucía.
- Metodología QFD (Quality Function Deployment – Despliegue de la Función de Calidad): Esta técnica (Akao, 1997) fue conceptualizada en un primer momento en Japón a finales de los 60, en la psicología comercial y el marketing, con el fin de que las empresas pudieran incorporar

en la fase de diseño de productos las preferencias de los consumidores en un entorno de competencia creciente. En la década de los 70, fue implementada exitosamente en diferentes industrias niponas, usualmente utilizada en el diseño de productos teniendo en cuenta las preferencias de los consumidores. A pesar de su reconocimiento en Japón, el primer antecedente en el desarrollo formal del método definitivo a nivel internacional fue el trabajo de Kogure y Akao (1983), que hizo que esta metodología comenzara a utilizarse en multitud de aplicaciones diferentes en todo el mundo, especialmente en USA. Una recopilación exhaustiva de los estudios de caso en la agroindustria puede consultarse en Benner et al. (2003). La utilización de QFD en la planificación pública en relación a la multifuncionalidad de los sistemas agrarios no ha sido encontrada en la literatura científica internacional y menos aún su combinación con ANP para tal fin. La novedosa combinación de QFD con ANP en esta Tesis ha permitido correlacionar las demandas de los ciudadanos hacia la agricultura con las funciones de no-mercado en el caso de los sistemas ganaderos lecheros, en base al conocimiento de expertos. Como resultado se ha obtenido la prioridad relativa de las diferentes funciones de no-mercado de los sistemas ganaderos según las preferencias sociales.

- El modelo LANDSCAPE Images: Es un marco de modelización y optimización multiobjetivo estática, basado en una aproximación desde la ingeniería agro-ecológica, para la exploración de la contribución potencial del uso de la tierra y la gestión del paisaje a la mejora de los resultados económicos y ambientales a nivel de parcela, explotación y paisaje de los sistemas agrarios (Groot et al., 2007). El modelo fue desarrollado para las explotaciones lecheras de los Países Bajos y se ha adaptado y utilizado en la presente Tesis para para generar y evaluar configuraciones alternativas de los sistemas agrarios y revelar trade-offs entre sus funciones de mercado y de no-mercado y entre las privadas y públicas. En definitiva, este modelo se ha usado, de forma alternativa a los modelos basados en ANP en el caso del olivar, para relacionar las técnicas agrarias implementadas por los ganaderos con el comportamiento multifuncional (económico, ambiental y social) de los sistemas agrarios, en este caso no sólo a nivel de explotación sino también a nivel de paisaje.
- El marco de los Beneficios Públicos/Privados Netos (BPPN): Se trata de una propuesta teórica y metodológica para asignar un valor de utilidad social total a formas de producción agraria alternativas y definir políticas eficientes para alcanzar las alternativas más sostenibles y evitar las insostenibles (Pannell, 2008; Pannell et al., 2012). Para ello, las funciones de cada alternativa se descomponen en privadas, que incluyen las funciones de mercado que afectan a los agentes productores, en este caso agricultores y ganaderos, y en públicas, que incluyen las funciones de mercado que afectan a los consumidores y las administraciones públicas y

las funciones de no-mercado, o externalidades, que afectan al conjunto de la sociedad. En función de la utilidad pública y privada, que agregadas constituyen la utilidad social de las diferentes alternativas de producción disponibles, este marco metodológico propone una serie de estrategias o políticas públicas, que van desde la extensión, o formación interna dentro de las empresas, de aquellas formas de producción que apliquen las prácticas más sostenibles socialmente y más beneficiosas empresarialmente, a los incentivos públicos positivos o negativos, el desarrollo tecnológico, y también el 'laissez-faire' a las empresas si las alternativas de producción no benefician al conjunto de la sociedad. En esta Tesis se ha integrado el marco BPPN con el resto de técnicas con el fin de evaluar y diseñar políticas y estrategias para lograr unos sistemas agrarios más sostenibles.

4. Estructura en capítulos

La Tesis Doctoral se ha estructurado en diferentes capítulos. Así, tras la presente 'Introducción general', en los siguientes cinco capítulos se reproducen cinco artículos publicados en revistas internacionales de impacto (uno de ellos se encuentra aún en revisión), cuyos resultados serán discutidos de modo global en el capítulo de 'Discusión general'. Finalmente se obtienen unas 'Conclusiones generales' de todo el trabajo realizado. Al final del documento se incluye también un capítulo con la 'Lista de publicaciones asociadas a la investigación realizada' y una 'Fe de erratas en artículos publicados' que han sido subsanadas en el presente documento. Cada capítulo es independiente en cuanto a numeración de los apartados, referencias, notas al pie, etc. A continuación se describen brevemente los cinco artículos:

Artículo 1: Este trabajo tiene como objetivo desarrollar y aplicar un modelo integrado de evaluación de la multifuncionalidad a nivel de explotación para el caso de la olivicultura en Andalucía. El propósito de este modelo es evaluar el comportamiento multifuncional de la olivicultura a nivel de explotación, incluyendo sus funciones económicas (tales como costes de producción, rendimiento y calidad del producto), sociales (desarrollo rural y empleo, identidad cultural y paisaje) y ambientales (erosión, fertilidad del suelo, contaminación de las aguas, biodiversidad, etc.) en función de las técnicas agrícolas aplicadas por los olivareros referidas a la plantación, manejo del suelo, riego, fertilización, tratamientos fitosanitarios, recolección y poda. El modelo se basa teóricamente en el Proceso Analítico de Red (ANP), un método de análisis de decisión multicriterio, alimentado por el conocimiento de 27 expertos, una encuesta realizada a 400 olivareros de las principales zonas productoras de aceite de oliva de Andalucía y una extensa revisión de la literatura internacional. Las posibilidades prácticas del modelo se ilustrarán con el fin de mejorar las políticas agroambientales orientadas a potenciar la multifuncionalidad del cultivo del olivo en Andalucía.

Artículo 2: En este artículo se desarrolla un marco metodológico integrado para el diseño de políticas públicas que promocionen técnicas agrícolas más sostenibles globalmente según los beneficios netos privados/públicos asociadas a las mismas. El trabajo se basa en el modelo desarrollado en el artículo anterior e incorpora el análisis de los beneficios netos privados/públicos. Así, se combinan dos modelos multicriterio ANP sobre las múltiples funciones de la olivicultura, en relación a las técnicas agrarias uno y a las demandas sociales otro, con un análisis económico y un marco de los Beneficios Públicos/Privados Netos (BPPN) para el diseño de políticas eficientes en términos de costes. Se consideran los beneficios y costes netos de todas las partes interesadas: los productores de aceitunas, los consumidores de aceite de oliva, las administraciones públicas y la sociedad en general. Las preferencias de la sociedad andaluza hacia la agricultura se obtuvieron mediante una encuesta a 409 ciudadanos.

Artículo 3: En este manuscrito se pretende integrar las múltiples demandas sociales hacia la agricultura en la evaluación la multifuncionalidad de la actividad agraria a nivel de paisaje, en el caso de la ganadería intensiva lechera de los Países Bajos, en concreto de la región de Northern Friesian Woodlands. Para ello se desarrolla una metodología que combina la valoración económica, la modelización integrada, el análisis de los todos actores afectados y la evaluación multicriterio. Los beneficios netos de mercado y no mercado son estimados para el conjunto de los actores afectados: agricultores, consumidores, gobierno y ciudadanos en general. Las funciones de no-mercado analizadas son la calidad del paisaje (variación en el número de especies de plantas en los pastizales e irregularidad en el patrón de los setos), el valor natural (diversidad de especies en el pasto y setos) y la salud ambiental (baja pérdida de nitrógeno). Las alternativas de paisajes vienen definidas por variables estructurales de las explotaciones como el tamaño y la fertilidad del suelo, y por variables de manejo como los regímenes de fertilización y siega de los pastos y la presencia o ausencia de setos alrededor de las parcelas. Las demandas de la sociedad neerlandesa se obtienen del Eurobarómetro, y las relaciones entre estas demandas y las funciones de no-mercado mediante entrevistas a 10 expertos usando una combinación de las metodologías QFD y ANP. El modelo de optimización multiobjetivo Landscape IMAGES se utiliza para generar y evaluar alternativas de paisajes y revelar trade-offs entre las funciones de mercado y de no-mercado.

Artículo 4: En este trabajo se propone un marco metodológico integrado para la evaluación ex-ante y la planificación de políticas públicas para una agricultura sostenible a nivel paisaje, de nuevo en el caso de explotaciones lecheras neerlandesas. El marco propuesto es una ampliación de la metodología desarrollada en el artículo anterior, que permite trasladar los beneficios netos de mercado y no-mercado en beneficios privados (de mercado para los ganaderos) y públicos (de mercado y no-mercado para el resto de agentes). El objetivo es explorar y seleccionar agro-paisajes potenciales sostenibles en función de los beneficios privados y públicos asociados a alternativas de uso del suelo. Finalmente se pretende definir mecanismos de políticas públicas eficientes para la mejora del beneficio social neto de los agro-paisajes. Para ello se integrará dentro de la metodología propuesta el marco de los Beneficios Públicos/Privados Netos (BPPN).

Artículo 5: En este artículo se aborda el problema de la escala espacial en la evaluación de la sostenibilidad de los sistemas agrarios y cómo la colaboración entre agricultores puede resultar en una mayor sostenibilidad de la actividad agraria sin menoscabar el beneficio privado de los agricultores. El origen del problema es que muchos servicios/funciones de los agro-ecosistemas son sólo aparentes a un nivel de escala espacial superior (paisaje) al nivel en el que se gestionan (explotación). Esto hace que sea imposible medir la contribución exacta de los agricultores a la prestación de estos servicios y determinar la magnitud de las ayudas públicas a nivel de agricultor. En este trabajo se propone un mecanismo institucional de compensación financiera entre los agricultores integrantes de un paisaje, basado en el criterio de Kaldor-Hicks y la mejora de Pareto y, que posibilita determinar cómo el apoyo público definido a nivel más alto se puede distribuir de manera justa y posibilitar una mejora óptima de Pareto. El mecanismo de compensación propuesto se ilustra de nuevo para el caso de la ganadería intensiva lechera de los Países Bajos. La evaluación del comportamiento multifuncional de los sistemas lecheros se basa en los modelos desarrollados en los dos artículos anteriores.

Los resultados de la presente Tesis Doctoral posibilitarán comprender mejor las interacciones entre las técnicas agrarias implementadas y los niveles de sostenibilidad global de los sistemas agrarios, y diseñar políticas agrarias y agro-ambientales más eficientes para potenciar la difusión de las técnicas agrarias más sostenibles y evitar la difusión de las menos deseables socialmente.

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Artículo 1.

Farm-level multifunctionality associated with farming techniques in olive growing: An integrated modeling approach

[Multifuncionalidad a nivel de explotación asociada con las técnicas agrarias en olivar: Una aproximación mediante modelización integrada]

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Abstract

This paper aims to contribute to methodology and practice for evaluating the multifunctionality of agriculture (MFA), including economic, environmental and social functions, by developing and applying an integrated farm-level multifunctionality model for the case of olive growing in Andalusia, the main olive growing region in the world. The purpose of this model is to assess the multifunctional performance of olive growing at farm-level according to the farming techniques implemented by olive growers, as land managers, in average conditions of olive cultivation in Andalusia. The proposed model is theoretically based on the Analytic Network Process (ANP), a Multi-Criteria Decision Analysis method. The model is built on the knowledge of 27 experts and an extensive review of the international literature, and it draws from empirical data gathered from a survey of 400 farmers in the main olive oil producing zones of Andalusia. The application of the model is illustrated with a view to improving olive growing agri-environmental policies oriented to multifunctionality in Andalusia. The modelling results indicate that, in general, olive growers are applying technical alternatives which are optimal for obtaining a high quality product, but to a certain extent they are neglecting the social impacts and, to an even greater extent, the environmental impacts of their activity. Despite the positive evolution over the last decade, there is still much room for improvement. The most sensitive groups of farming practices generally in need of changes are soil management, irrigation and fertilization. The results also make it clear that an improved economic performance is not incompatible with social objectives, such as rural development and employment, and with the environmental protection of soil, water and biodiversity. Finally, the results indicate the higher multifunctional performance of some alternative farming packs. This is the case for both integrated production and intensive agriculture.

Keywords: Multifunctionality; integrated evaluation; Analytic Network Process (ANP); olive growing; farming practices.

Highlights: • An integrated approach is required for evaluation of MFA; • We develop and apply a farm-level integrated ANP model for olive growing in Andalusia; • The model draws from expert knowledge and empirical data on olive farms; • Sensitive practices, best techniques and optimal packs were identified; • There is much room for improvement in techniques, especially in environmental terms.

1. Introduction

The concept of multifunctionality of agriculture (MFA) is complex and open to diverse definitions and interpretations (Cairol et al., 2009; Hediger and Knickel, 2009; Renting et al., 2009). However there is a general consensus on what it entails: agriculture fulfils multiple functions ranging from producing food and fibers (with economic 'monetary' value for producers and consumers) to producing multiple environmental, social and additional economic outputs (usually non-remunerated in the market but with an impact on the welfare of citizens in general) (Wiggering et al., 2006; Renting et al., 2009). Olive growing is no exception and it is expected to play a multifunctional role in society (Arriaza et al., 2007; Parra-López et al., 2008b; Fleskens et al., 2009).

Evaluating MFA poses problems of high complexity, uncertainty and risk. The complexity of the interactions between the functions of agriculture and agro-ecological processes, institutional conditions and technical restrictions (Zander et al., 2008) prevents us from building excessively simple models of reality if we wish to avoid considerable loss of information. Since there is a trade-off between simplicity and accuracy (Janssen and van Ittersum, 2007), research should aim at the simplification of models to the level of accuracy required for problem-solving and decision support (Zander et al., 2008). The evaluation of MFA is a social decision-making process in which the conflicting values and interests of different groups and communities must be considered (Martinez-Alier et al., 1998). This process is rife with uncertainty due to the lack of hard data for many relevant processes and interactions. It also involves an element of risk because of what is at stake, since decisions usually affect not only the current generation but also those that follow, and many of these decisions, especially those affecting the environment, may be irreversible (Funtowicz and Ravetz, 1993). Moreover MFA evaluations usually have to be carried out as a matter of urgency (Funtowicz and Ravetz, 1991).

In this context, an 'integrated' approach to MFA evaluation is required. This approach needs to be: a) holistic, to deal with complexity by including as many relevant aspects and facets of reality as possible, allowing us to manage the possible uncertainties, contradictions and inconsistencies; b) systemic, to understand the underlying mechanisms that link the multiple functions of agriculture to the characteristics of farming systems, and to forecast results for new scenarios; c) integrative, to deal with models of different levels of complexity, ranging from statistical to expert-based; and d) transdisciplinary, to incorporate knowledge and facilitate the interchange of information between diverse scientific disciplines, and between scientists and non-academic stakeholders, such as managers, administrators, and the general public.

A number of tools and approaches are available for evaluating the multiple functions of agriculture. They are mainly farm-level bio-economic modelling techniques (Janssen and van Ittersum, 2007; Rossing et al., 2007; Zander et al., 2008), mostly based on mathematical programming or optimization models (Janssen and van Ittersum, 2007). Despite this considerable background, most of these approaches do not specifically target an integrated evaluation of MFA, due to a lack of social goals, an underrepresentation of biotic and landscape topics within the environmental and economic goals, a weak interdisciplinary focus, and scarce final-user information targeting and involvement (Rossing et al., 2007). Whilst it is true that on the specific topic of the functions associated with the olive farming techniques implemented by farmers the literature is abundant, the studies are rarely integrated. In general, they cannot be considered holistic as they usually focus on just one or a few farming practices and functions and the rest are simply considered to fall outside the model. Moreover, the systemic analysis is weak since the relationships between farming techniques and functions are usually established on the basis of static statistics for certain fixed experimental conditions, thus not allowing for the extrapolation of results to other scenarios. Furthermore, the literature is centered on certain topics within closed mono-disciplines. The main topics are the impact of soil management on soil properties (Francia Martínez et al., 2006; Álvarez et al., 2007; Fleskens and Stroosnijder, 2007; Castro et al., 2008; Duarte et al., 2008; Gómez et al., 2009; Moreno et al., 2009; Nieto et al., 2010); of irrigation on olive yield (Melgar et al., 2008; Weissbein et al., 2008; Fernandes-Silva et al., 2010; Ramos and Santos, 2010; Caruso et al., 2011); of irrigation on olive quality (Berenguer et al., 2006; D'Andria et al., 2008; Khattab et al., 2009; Stefanoudaki et al., 2009); and of fertilization on olive yield (Tabatabaei, 2006; Erel et al., 2008; Morales-Sillero et al., 2008; Fernández-Escobar et al., 2009). These topics are essentially related to environmental and economic functions of olive growing. There is less research available on other topics, especially social functions such as rural development and employment, or cultural identity and landscape. Moreover, the usability of the results obtained for policy evaluation and design and for decision-making by farmers is in general low, since the data obtained are generally very technical and difficult for non-expert decision-makers to use. A few studies have taken a more explicitly holistic approach, such as those of (Parra-López et al. (2007), 2008b); Gómez-Limón and Arriaza-Balmón (2011)), which analyse a broad range of functions. However, these precedents lack a systemic perspective since the multiple functions of olive growing are not explicitly linked to the specific farming techniques implemented by farmers, but to alternative types of agriculture as a whole, such as conventional, organic, integrated, traditional, semi-intensive and intensive agriculture. In summary, to our knowledge no information is available from an integrated perspective.

Some authors, such as (Hernández and Cardells (1999); Parra-López et al. (2008b)), indicate that one useful and increasingly common approach to dealing with complex environmental problems such as the integrated evaluation of MFA is Multi-Criteria Decision Analysis – MCDA (Figueira et al., 2005). In particular, the Analytic Network Process, or ANP (Saaty, 2001), is a flexible and powerful discrete MCDA method that allows us to deal with multiple criteria and stakeholders, and the incorporation of qualitative, subjective and intangible information into the evaluation process, for instance in the form of experts' knowledge, as well as quantitative and hard-data information when available.

With all this in mind, one objective of this paper is to develop an integrated model for the evaluation of MFA. This integrated model evaluates the multifunctional performance of olive growing at farm-level according to the farming techniques implemented by olive farmers in the case of Andalusia, the most important olive-growing region of Spain and the world. The proposed model is theoretically based on ANP, whose use will be illustrated. The model is built on the basis of expert knowledge and an extensive review of the international literature, and draws from empirical data gathered from a survey of farmers in the main olive oil producing zones of Andalusia. The second objective of the paper is to apply this integrated model to improving the design of agri-environmental policies oriented to multifunctionality. Hence, some relevant issues for policy design will be investigated: a) determining the most sensitive farming practices, i.e. those with the highest potential to affect the multifunctional performance of olive farms, and the best technical alternatives, i.e. the best way to implement these farming practices; b) identifying optimal packs of farming techniques according to their multifunctional performance and defining advisable changes to improve average farming practices, taking into account developments in recent years; and c) evaluating the multifunctional performance of alternative farming packs, such as Integrated Production, to establish whether they are superior from a multifunctional point of view to average, i.e. standard, agriculture.

2. Material and methods

2.1. Study setting: The Andalusian olive-growing sector

Olive agriculture is an important economic activity in Mediterranean countries, especially in Spain. In the period 2005-2010, this country accounted for 25% of the total olive surface area and 36% of world production (FAO, 2012). It is primarily an extensive cultivation which, in addition to its economic relevance, fulfils a set of important environmental and socio-cultural functions. These additional functions are even more marked in marginal sloping areas where olive orchards are mainly managed in a traditional low-intensity manner (Duarte et al., 2008). Given its highly relevant territorial presence and its importance from an economic, social and environmental perspective in this country, any change in the farming techniques implemented may have a significant impact on the multifunctional performance of olive growing and the welfare of multiple economic agents and society in general. Evaluating the multifunctional performance of olive growing in relation to current and potentially implementable farming techniques in the region is therefore of the greatest interest.

Andalusia, in the south of Spain, is the world-leading olive growing region, representing 80% of total olive production in Spain, 37% in the EU-27 and 25% at worldwide level in 2008 (MARM, 2010; FAO, 2011). Olive agriculture is a strategic sector for the economy and the socio-territorial cohesion of Andalusia. The olive is the single most important crop in the region, covering 32% of the agricultural area (MARM, 2010) and providing 28% of Andalusian fruit and vegetable production (CAP, 2012). Moreover, it is a social cultivation that generates around one third of agricultural employment, of which approximately 47% is family-based (CAP, 2009). In addition to its economic and social importance, olive agriculture has a high potential for affecting the environment in the region due to its wide territorial presence, influencing the welfare of Andalusian society in a significant manner (Parra-López et al., 2008b). Most of the olive crop is cultivated in a traditional extensive manner although an increasing surface area (15% according to our internal data) is cultivated more intensively with a massive use of productive inputs. Moreover, a growing surface area is now dedicated to alternative methods of agriculture such as Integrated Production (Parra-López, 2003), and certified quality systems such as Protected Designation of Origin (PDO). These alternatives to conventional techniques are adopted by around 16% of Andalusian olive growers (Hinojosa-Rodríguez et al., 2013). The modal olive farm in Andalusia has these structural characteristics (Hinojosa-Rodríguez et al., 2013): Total farm area, 1-5 ha; type of cultivation, traditional; yield, 4000-6000 kg olives/ha; age of the olive plantation, 10-50 years; labor, family and temporary employees; destination of the product, olive oil; land slope, low; inserted cultivations, no; livestock management, no; main customer, first degree cooperative mills; main customer base location, Andalusia.

2.2. The ANP modelling process

This section illustrates the creation of the integrated model based on the ANP method (Saaty, 2001). ANP is a sophisticated and well-established methodology, so here only the main features that match the objectives of the paper will be illustrated. For the practical implementation of ANP, interested readers are referred to Saaty (2003) and the software package Superdecisions (www.superdecisons.com). The olive model is specified for the average agro-climatic, environmental and socio-institutional conditions of olive cultivation in Andalusia. ANP is a generalization of the Analytic Hierarchy Process, AHP (Saaty, 1980a), taking into account dependences and feedback. Therefore, many analogies can be drawn between ANP and AHP. ANP proposes an analysis and synthesis process for modelling and solves a multi-criteria problem. This process consists of a series of steps or phases detailed in the next subsections.

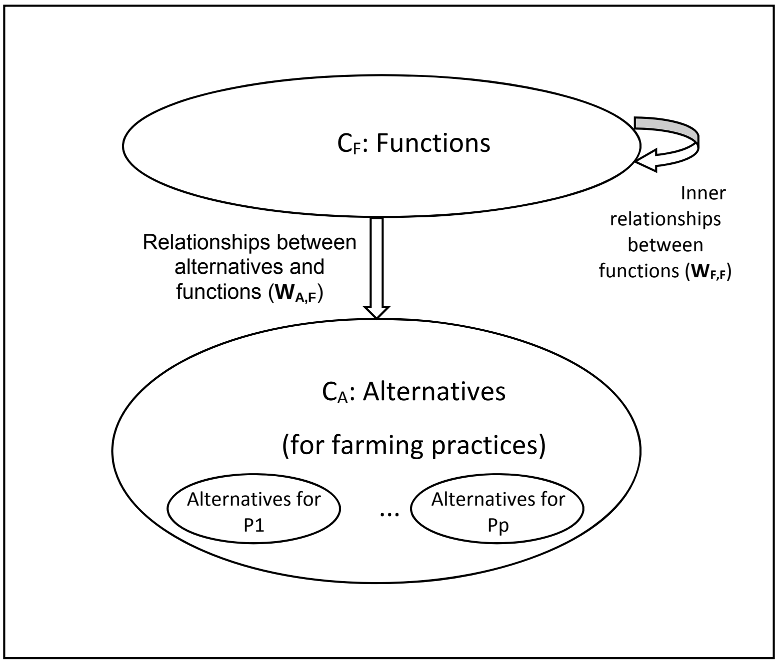
2.2.1. Model specification

A model is defined in ANP as a network of decisional elements and clusters of elements interconnected by dominance/contribution relationships, in our case farming techniques and multiple functions at farm-level. The definition of the network structure of the proposed integrated model was a dynamic process involving three phases: 1) defining and clustering of the most relevant farming practices and technical alternatives, and their potential functions; 2) establishing *a priori* the potential relationships between them, without quantifying them, on the basis of the international literature; and 3) pre-testing and refining the proposed structure and relationships. The final structure of the model is set out in Figure 1. It consists of: a) a Cluster of Functions (C_F), containing 11 relevant farm-level functions of agriculture relative to the economic, social and environmental dimensions; b) a Cluster of Farming practices (C_P), consisting of 22 olive farming practices, referring to 7 main groups of practices in olive growing ranging from planting to pruning; and c) a Cluster of Alternatives (for farming practices) (C_A), which consists of the technical alternatives for each farming practice. For instance, for practice P1, 'Olive variety', there are 5 technical alternatives, ranging from A1(P1) 'Picual' to A5(P1) 'Picudo'. A farming technique would be the use of the technical alternative 'Picual' for the farming practice 'olive variety'. More detailed information on functions, practices and alternatives will be given in the next sections.

The relationships between the elements of an ANP model can be represented as a supermatrix (Table 1). The submatrices of this supermatrix represent the relationships of contribution of some elements to others or, inversely, of dominance over others. A cluster is related to another cluster (outer dependence) or to itself (inner dependence) if at least two elements of the cluster(s) are related through a dominance relationship. $\mathbf{W}_{\mathbf{A,F}}$ accounts for the outer contribution of the alternatives for each farming practice (A) to achieve each function (F); for instance, we can establish whether the olive variety Picual is better/equal/worse than Picudo for obtaining a high olive yield. $\mathbf{W}_{\mathbf{F,F}}$ represents the inner relationships or interrelations between functions; for instance, the function 'olive yield', expressed in terms of kg of olives ha^{-1}, can contribute to the function 'rural development and employment'. Finally, **I** is a unity submatrix which shows that the alternatives for the farming practices, i.e. the farming techniques, are inner independent from a dominance/contribution point of view. That is to say, the technical alternatives for a given farming practice are not interrelated. However, they are technically outer restricted: the validity of a particular combination of farming techniques to be jointly implemented, referred to henceforth as a 'farming pack', is conditioned by its technical feasibility. For instance, to irrigate or not to irrigate are independent alternatives. However, it is impossible not to irrigate and still apply fertilizers through irrigation water (fertirrigation)

Figure 1. Model network structure

a) Supermatrix netwok



b) Control submatrix network

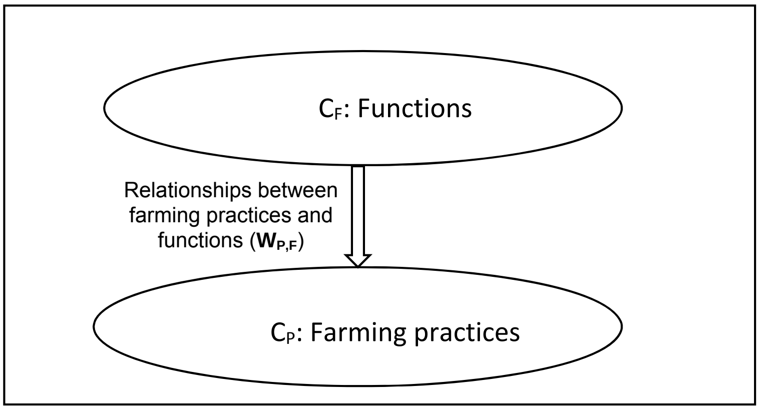


Table 1. Supermatrix of the ANP model

a) Supermatrix at cluster level

		C_F: Functions	C_A: Alternatives (for farming practices)		
			P1	...	Pp
C_F: Functions		$\mathbf{W_{F,F}}$	0		
C_A: Alternatives (for farming practices)	P1 ... Pp	$\mathbf{W_{A,F}}$	**I**		

b) Supermatrix at element level

			C_F: Functions				C_A: Alternatives (for farming practices)								
							P1				...	Pp			
			F1	F2	...	Ff	A1(P1)	A2(P1)	...	Aa1(P1)	...	A1(Pp)	A2(Pp)	...	Aap(Pp)
C_F: Functions		F1	$W_{F1,F1}$	$W_{F1,F2}$	...	$W_{F1,Ff}$	0	0	...	0	...	0	0	...	0
		F2	$W_{F2,F1}$	$W_{F2,F2}$	...	$W_{F2,Ff}$	0	0	...	0	...	0	0	...	0
		...	...	...	...	...	...	...	...	...	...	...	...	...	...
		Ff	$W_{Ff,F1}$	$w_{Ff,I2}$	...	$w_{Ff,Ff}$	0	0	...	0	...	0	0	...	0
C_A: Alternatives (for farming practices)	P1	A1(P1)	$w_{A1(P1),F1}$	$w_{A1(P1),F2}$	...	$w_{A1(P1),Ff}$	1	0	...	0	...	0	0	...	0
		A2(P1)	$w_{A2(P1),F1}$	$w_{A2(P1),F2}$	...	$w_{A2(P1),Ff}$	0	1	...	0	...	0	0	...	0
		...	...	...	...	...	...	...	...	...	...	...	...	...	...
		Aa1(P1)	$w_{Aa1(P1),F1}$	$w_{Aa1(P1),F2}$	...	$w_{Aa1(P1),Ff}$	0	0	...	1	...	...	0	...	0
	...	...	...	...	...	...	...		...		...	...	...	...	...
	Pp	A1(Pp)	$w_{A1(Pp),F1}$	$w_{A1(Pp),F2}$	...	$w_{A1(Pp),Ff}$	0	0	...	0	...	1	0	...	0
		A2(Pp)	$w_{A2(Pp),F1}$	$w_{A2(Pp),F2}$	...	$w_{A2(Pp),Ff}$	0	0	...	0	...	0	1	...	0
		...	...	...	...	...	...	...	...	...	...	...	...	...	...
		Aap(Pp)	$w_{Aap(Pp),F1}$	$w_{Aap(Pp),F2}$	...	$w_{Aap(Pp),Ff}$	0	0	...	0	...	0	0	...	1

The control submatrix (Table 2) consists of just one submatrix, $\mathbf{W_{P,F}}$, which reflects the different contribution of the practices to each function. It is needed to weight the column vectors of $\mathbf{W_{A,F}}$, since the practices may not all contribute equally to the achievement of a given function. For instance, olive variety may be more/equal/less important than soil management to achieve a high olive yield. In order to facilitate the evaluation of relationships between elements, some parts of the columns of the supermatrix and control submatrix were set *a priori* at zero if the relations they represented were not possible based on previous literature or due to technical restrictions.

Table 2. Control submatrix of the ANP model

a) Control submatrix at cluster level

	C_F: Functions
C_P: Farming practices	$\mathbf{W_{P,F}}$

b) Control submatrix at element level

		C_F: Functions			
		F1	F2	...	Ff
C_P: Farming practices	P1	$w_{P1,F1}$	$w_{P1,F2}$	...	$w_{P1,Ff}$
	P2	$w_{P2,F1}$	$w_{P2,F2}$	...	$w_{P2,Ff}$
	...	...	...	...	...
	Pp	$w_{Pp,F1}$	$w_{Pp,F2}$	...	$w_{Pp,Ff}$

2.2.2. Evaluation of relationship matrices

Once the structure of the model is defined, the next step is to evaluate the magnitude of the relationships between its elements. ANP allows this evaluation to be based on hard data, if available, or soft data in the form of expert knowledge and/or stakeholder preferences. In the former case, the data can be adapted, normalized and introduced into the relationship matrices directly. In the latter case, the supermatrix and control submatrix entries can be assessed by two different methods: 1) by relative measurement, through 'pairwise comparisons' of the contribution of two row elements (e.g. alternatives for a practice) to a given column element (e.g. function), if the number of elements to compare is less than 7±2 (Saaty, 1980b; Forman and Selly, 2001); 2) by absolute measurement, through 'direct rating', if the elements to compare are more than 7±2, which increases the inconsistency of responses due to human short-term memory limitations (Larichev et al., 1995; Bottomley and Doyle, 2001; Forman and Selly, 2001). The pairwise comparisons method has some important properties, such as measuring the consistency of the evaluators' judgements, but in complex models can be inoperative. Conversely, the direct rating method does not account for consistency but is more operative and practical in such cases.

In our case, the evaluation was based on expert knowledge due to the technical nature of the information required and the lack of previous *ad hoc* hard data in most of the topics analyzed. 27 experts were selected according to their experience in the olive systems of Andalusia. Their fields of specialization were the olive sector (8 experts), agricultural economics (7), olive soil management (4), olive pests and diseases (3), olive growing (2), fertilization (1), olive quality (1) and organic olive production (1). Listed by profession, 16 were researchers from public research centers, 5 practitioners of the olive growing sector, 3 researchers from universities and 3 government employees. The experts individually filled in the parts of the supermatrix and the control submatrix for which they had knowledge and expertise. They were asked to evaluate the relationships though 'direct rating' since the number of elements to compare surpassed the recommended limit for many items, e.g. 22 practices for each of the 11 functions. In particular, the rating scale was used to evaluate the strength of the relationships ranging from 1 (very weak) to 9 (very strong), reserving 0 for the absence of any relationship (Parra-López et al., 2008c). For instance, in the matrix $\mathbf{W}_{A,F}$, the alternative A1(P1) Picual could be related strongly to the function F1, lower production costs, according to an expert ($W_{A1(P1),F1}$ would be 9 in Table 1b).

2.2.3. Aggregation of the individual relationship matrices

The individual relationship matrices need to be condensed into one aggregated supermatrix and one control submatrix. Although there are diverse aggregation methods (Ramanathan and Ganesh, 1994), they can be calculated as the arithmetic mean of the individual priorities, the AIP method, recommended for social problems (Forman and Peniwati, 1998; Gómez-Limón and Atance, 2004). For the supermatrices and the control matrices this would be: $w_{i,j(aggr)} = \sum_{\forall i,j} w_{i,j(e)}/E$, where $w_{i,j}$ is an element of a submatrix; *e* is an expert; and *E* is the number of experts. Relationships not evaluated by individual experts due to their lack of knowledge and expertise were not included when calculating the mean. In this way, the aggregated submatrices $\mathbf{W}_{A,F(aggr)}$, $\mathbf{W}_{P,F(aggr)}$ and $\mathbf{W}_{F,F(aggr)}$ were obtained. As mentioned previously, the practices do not all contribute equally to a given function. Therefore the column vectors of the aggregated submatrix $\mathbf{W}_{A,F(aggr)}$ must be weighted by the aggregated control submatrix, $\mathbf{W}_{P,F(aggr)}$. For instance, the segment of the column vector corresponding to the contribution of the alternatives for practice 1 to function 1 must be multiplied by $w_{P1,F1}$, thus obtaining the weighted submatrix $\mathbf{W}_{A,F(aggr,weigh)}$. Finally each column of the complete supermatrix must be normalized, in other words its columns must add up to one to be stochastic (Niemira and Saaty, 2004), thus obtaining one weighted supermatrix.

2.2.4. Synthesis of the multifunctional performance associated with farming packs

The farm-level multifunctional performance associated with a given farming pack is calculated by synthesizing the information contained in the weighted supermatrix. The particular mathematical properties of reducibility, primitivity and cyclicity of this supermatrix (Saaty and Takizawa, 1986; Lee and Kim, 2000; Karsak et al., 2003; Kahraman et al., 2006; Parra-López et al., 2008c) make it advisable to carry out this synthesis as follows:

1) Calculate the matrix of interdependent relationships between the alternatives for practices and the functions ($\mathbf{W}_{A,F}'$): This matrix represents the contribution of the farming techniques to each function once the inner relationships between functions have been taken into consideration. It is defined as: $\mathbf{W}_{A,F}' = \mathbf{W}_{A,F(aggr,weigh)} . \mathbf{W}_{F,F(aggr)}$. For a partial view of $\mathbf{W}_{A,F}'$ see Table 3.
2) Calculate the performance on the multiple functions associated with a farming pack ($\mathbf{pf}_{(pack)}$): This is a row vector defined as: $\mathbf{pf}_{(pack)} = \mathbf{pack}.\mathbf{W}_{A,F}'$, where ***pack*** is a row vector of the farming techniques that define the farming pack. For instance, in our model, **pack** = (1,0,0,0,0; 1,0,0,0; ...; 1,0) means the combined use of Picual as the variety, bare soil through constant tillage as the soil management technique, ... and traditional pruning.

Table 3. Matrix of interdependent relationships between alternatives for practices and functions ($W_{A,F}'$) (partial view)

			C_F: Functions										
			F1. Lower production costs	F2. Olive yield	F3. Product quality	F4. Rural development & employment	F5. Cultural identity and landscape	F6. Less soil erosion	F7. Soil water retention capacity	F8. Soil Fertility	F9. Less water contamination	F10. Less water consumption	F11. Biodiversity
C_A: Technical alternatives for farming practices	P1. Olive variety	A1(P1). Picual	0.0044	0.0100	0.0210	0.0084	0.0002	0.0000	0.0000	0.0000	0.0027	0.0085	0.0000
		A2(P1). Hojiblanca	0.0045	0.0085	0.0233	0.0081	0.0002	0.0000	0.0000	0.0000	0.0028	0.0087	0.0000
		A3(P1). Lechín de Sevilla	0.0052	0.0073	0.0213	0.0076	0.0002	0.0000	0.0000	0.0000	0.0032	0.0099	0.0001
		A4(P1). Lechín de Granada	0.0052	0.0075	0.0220	0.0077	0.0002	0.0000	0.0000	0.0000	0.0032	0.0099	0.0001
		A5(P1). Picudo	0.0047	0.0076	0.0238	0.0078	0.0002	0.0000	0.0000	0.0000	0.0029	0.0091	0.0000
	P2. Soil manage-ment	A1(P2). Bare soil, conventional farming (constant tillage)	0.0616	0.0670	0.0000	0.0535	0.0693	0.0775	0.0806	0.0764	0.0756	0.0756	0.0762
		A2(P2). Bare soil, no tillage, weed control with herbicides	0.0753	0.0793	0.0000	0.0536	0.0620	0.0901	0.0930	0.0814	0.0753	0.0877	0.0771
		A3(P2). Bare soil, little tillage or shallow tillage, weed control with herbicides	0.0837	0.0917	0.0000	0.0607	0.0687	0.1047	0.1107	0.0960	0.0883	0.0993	0.0912
		A4(P2). Soil covered by spontaneous or cultivate plants	0.1171	0.1332	0.0000	0.0824	0.0845	0.1562	0.1706	0.1460	0.1322	0.1393	0.1392
	...	...	...	...	...	...	...	...	...	...	...	...	...
	P22. Pruning intensity	A1(P11). Traditional, severe, each 1-2 years	0.0435	0.0306	0.0000	0.0364	0.0341	0.0303	0.0265	0.0217	0.0296	0.0490	0.0225
		A2(P11). Low intensity pruning, every 2-3 years	0.0554	0.0393	0.0000	0.0361	0.0292	0.0368	0.0321	0.0263	0.0329	0.0503	0.0272
		Sum	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*

Subsequently, the maximum (or minimum) performances achievable for each function F can be defined by implementing the optimal (or worst) technical alternatives for each farming practice that maximize (or minimize) performance in this function and that constitute a technically feasible combination. For instance, for function F1, 'Lower production costs', the optimal farming techniques would be Lechín de Granada as the variety -A4(P1)-, soil covered -A4(P2)-, ... and low intensity pruning -A2(P22)- (Table 3, first column). In this way, 11 optimal (or worst) farming packs can be defined, one for each function. These maximum and minimum values demarcate the range of potential performance achievable for each function in current technological conditions and according to our model. This allows evaluation of the farm-level performance in each function associated with a given farming pack in relative terms, by assigning 1 to the maximum performance and 0 to the minimum performance. In this way, the value of the performance associated with a farming pack in any function will range from 0 to 1. Furthermore, the economic performance of a given farming pack can be calculated as the average of its performances for the economic functions (F1 to F3). The same process can be applied for social (F4 and F5) and environmental (F6 to F11) performances. Finally, the global performance associated with a farming pack can be calculated as the average of its economic, social and environmental performances.

2.3. Sensitivity of the farming practices

One objective of this paper is to delimit the most sensitive farming practices, i.e. those with the highest potential to affect the multifunctional performance of olive growing at farm-level. These are the practices for which changing the way they are carried out, in other words the technical alternatives by which they are implemented, all other factors remaining equal, will have the highest incidence on the performance in the diverse functions of agriculture. To measure this, we propose a 'sensitivity index', $S_{(P,F)}$, for a given practice *P* over a function *F*, as follows:

$$S_{(P,F)} = \sum_{\forall a_{(P,F)} \neq amax_{(P,F)}} \frac{\left[pf\left(amax_{(P,F)}\right) - pf\left(a_{(P,F)}\right)\right]}{(A_P - 1)}$$

where *pf(amax*$_{(P,F)}$*)* is the maximum performance achievable in function F by changing only the technical alternatives for farming practice P; this is achieved for this function when implementing the technical alternative *amax*$_{(P,F)}$ for this practice; *pf(a*$_{(P,F)}$*)* is the performance in function F when implementing the technical alternative $a_{(P,F)}$, other than $amax_{(P,F)}$; and A_P is the number of alternatives for practice P, including $amax_{(P,F)}$. The S index measures the variation of the performance in a given function relative to the maximum performance when changing the technical alternatives for a given practice. Furthermore, for a given farming practice it is possible to calculate its S index for the economic dimension as the average of its S indices for the economic functions. The same applies for the social and environmental S indices. The 'mean sensitivity' of a farming practice is the average of the economic, social and environmental S indices.

3. Results

3.1. Sensitive farming practices and best technical alternatives

According to the sensitivity analysis, soil management –P2– is by far the most sensitive farming practice with a mean sensitivity of 0.2618 (Table 4, last column). Any change in the way soil management is carried out, i.e. in the technical alternative used, could substantially increase/decrease the performance of olive growing in almost all the functions analyzed, especially in the environmental ones. In this sense, the technical alternative 'soil covered by plants' –A4(P2)– produces, *ceteris paribus*, the maximum performance by far in almost all the functions compared to the three 'bare soil' options (Figure 2.P2). The only exception is product quality –F3– which is not influenced by the soil management technique (S index = 0.0000; Table 4). Quality is defined on the basis of oil yield and the organoleptic, physical, chemical and nutritional attributes of the olive oil subsequently produced. Of the bare soil techniques, little or shallow tillage –A3(P2)– is the best alternative, especially for the environmental functions. Conventional tillage –A1(P2)–, i.e. constant tillage, is the worst technical alternative (Figure 2.P2). These results are in agreement with previous literature which highlights the benefits of soil cover for controlling soil erosion and improving the physico-chemical and biological characteristics of the soil (Kosmas et al., 1997; Gómez et al., 2002; Gómez et al., 2003; Gómez et al., 2004; Hernández et al., 2005; Francia Martínez et al., 2006; Fleskens and Stroosnijder, 2007; Rodríguez-Lizana et al., 2007).

Table 4. Sensitivity indices for the farming practices

		GF1. Economic functions			GF2. Social functions		GF3. Environmental functions						
Group of practices	**Farming practices**	**F1. Lower production costs**	**F2. Olive yield**	**F3. Product quality**	**F4. Rural development & employment**	**F5. Cultural identity and landscape**	**F6. Less soil erosion**	**F7. Soil water retention capacity**	**F8. Soil fertility**	**F9. Less water contamination**	**F10. Less water consumption**	**F11. Biodiversity**	***Mean sensitivity***
GP1.Planting	P1. Olive variety	0.0029	0.0127	0.0073	0.0051	0.0001	0.0000	0.0000	0.0000	0.0023	0.0066	0.0000	0.0039
GP2. Soil management	P2. Soil management	0.2634	0.3035	0.0000	0.2348	0.1282	0.4158	0.4482	0.4232	0.4211	0.3774	0.4041	0.2618
GP3. Irrigation	P3. Irrigation	0.1996	0.1573	0.0254	0.0899	0.1038	0.1001	0.0922	0.0985	0.0530	0.3009	0.0848	0.1153
	P4. Irrigation system	0.0152	0.0138	0.0000	0.0156	0.0036	0.0012	0.0012	0.0063	0.0181	0.0323	0.0054	0.0100
	P5. Timing of irrigation	0.0196	0.0173	0.0137	0.0292	0.0105	0.0000	0.0000	0.0000	0.0098	0.0277	0.0001	0.0143
	P6. Analysis of the quality of the irrigation water	0.0154	0.0336	0.0184	0.0362	0.0117	0.0233	0.0250	0.0436	0.0440	0.0201	0.0408	0.0264
GP4. Fertilization	P7. Fertilization	0.0163	0.1998	0.0479	0.1375	0.0842	0.1032	0.1175	0.0802	0.0441	0.0871	0.0073	0.0907
	P8. Method for the application of fertilizers	0.0308	0.0905	0.0105	0.0604	0.0429	0.0580	0.0557	0.0667	0.0106	0.0397	0.0539	0.0477
	P9. Fertilizers used	0.0923	0.1133	0.0000	0.0702	0.0225	0.1375	0.1668	0.1362	0.1348	0.1459	0.1261	0.0854
	P10. Analysis of soil or leaf before fertilization	0.0033	0.0000	0.0356	0.0103	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0060
GP5. Phytosanitation	P11. Phytosanitation	0.0597	0.0551	0.0933	0.0318	0.0424	0.0715	0.0673	0.1264	0.1828	0.0045	0.1713	0.0701
	P12. Treatment of olive fruit fly (Bractrocera oleae)	0.0002	0.0025	0.0019	0.0019	0.0051	0.0039	0.0039	0.0055	0.0064	0.0012	0.0066	0.0032
	P13. Treatment of olive moth (Prays oleae)	0.0001	0.0033	0.0009	0.0051	0.0109	0.0068	0.0064	0.0102	0.0138	0.0006	0.0137	0.0060
	P14. Treatment of peacock spots (Spilocaea oleagina)	0.0010	0.0027	0.0077	0.0083	0.0077	0.0056	0.0054	0.0101	0.0137	0.0014	0.0127	0.0067
	P15. Timing of phytosanitary treatments	0.0068	0.0069	0.0164	0.0215	0.0174	0.0071	0.0067	0.0110	0.0149	0.0007	0.0146	0.0129
	P16. Localization of phytosanitary treatments	0.0099	0.0010	0.0000	0.0027	0.0049	0.0100	0.0095	0.0152	0.0206	0.0010	0.0203	0.0067
GP6. Harvesting	P17. Timing of harvest	0.0000	0.0000	0.1516	0.0438	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0241
	P18. Method for collecting fallen olives from ground	0.0448	0.0153	0.2717	0.1170	0.2980	0.0476	0.0289	0.0316	0.0393	0.0024	0.0456	0.1169
	P19. Method for picking the olives from the trees	0.0860	0.0094	0.0315	0.0486	0.0691	0.0151	0.0015	0.0102	0.0126	0.0007	0.0148	0.0368
	P20. Separation of the olives from ground and trees	0.0133	0.0092	0.4204	0.0709	0.0925	0.0099	0.0096	0.0051	0.0073	0.0009	0.0075	0.0787
	P21. Ways of carrying the olives to the mill	0.0054	0.0000	0.0688	0.0205	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0118
GP7. Pruning	P22. Pruning intensity	0.0718	0.0490	0.0000	0.0032	0.0352	0.0410	0.0331	0.0316	0.0267	0.0092	0.0329	0.0295

= Terciles for the sensitivity indices by function (column): low, medium and high sensitivity. See text for explanation of the S (sensitivity) index.

Note: Bars represent graphically the sensitivity indices.

Figure 2. Multifunctional performance associated with the highly sensitive farming practices. For a definition of multifunctional performance and sensitive farming practices see sections 2.2.4 and 3.1, respectively

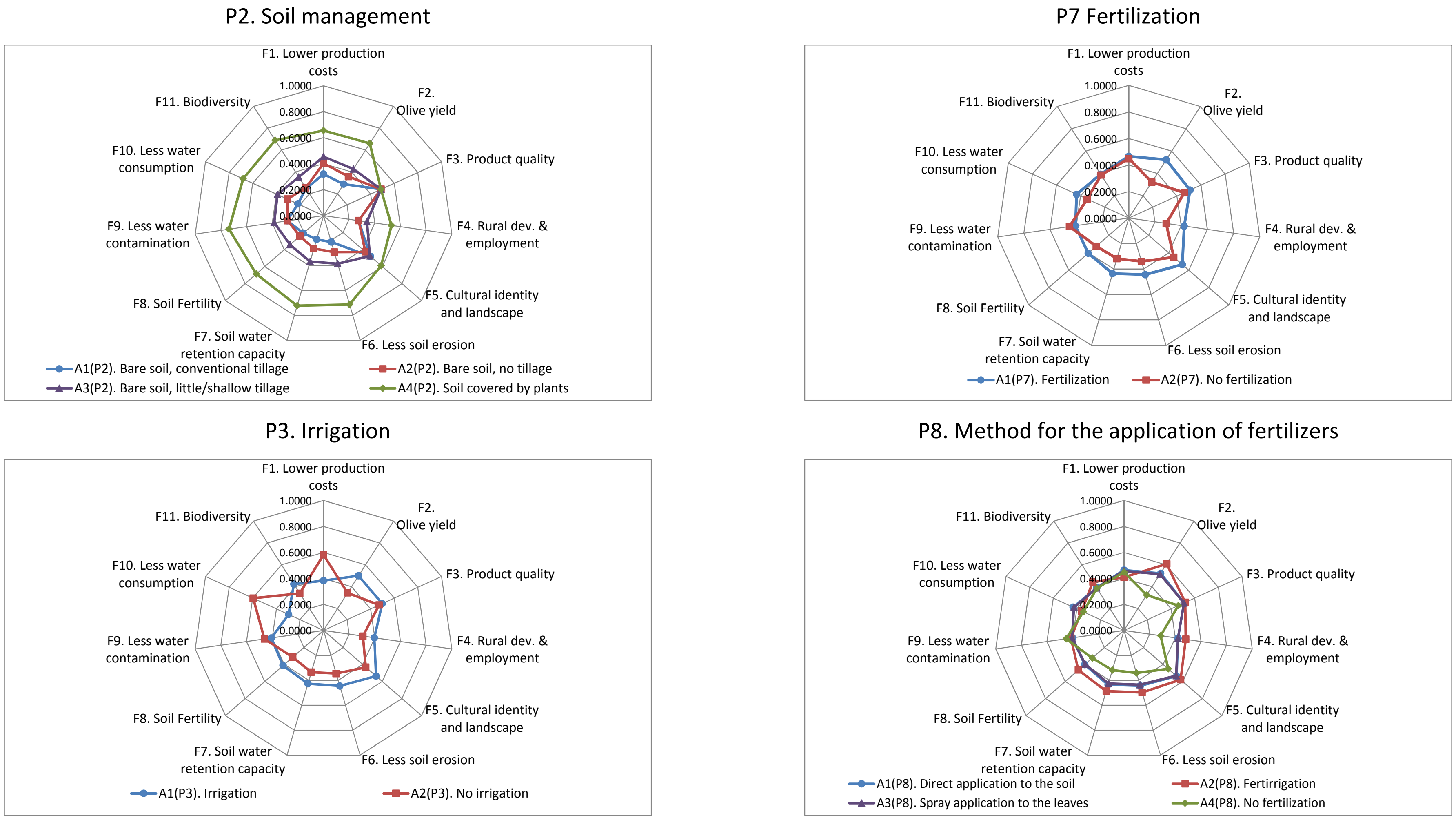
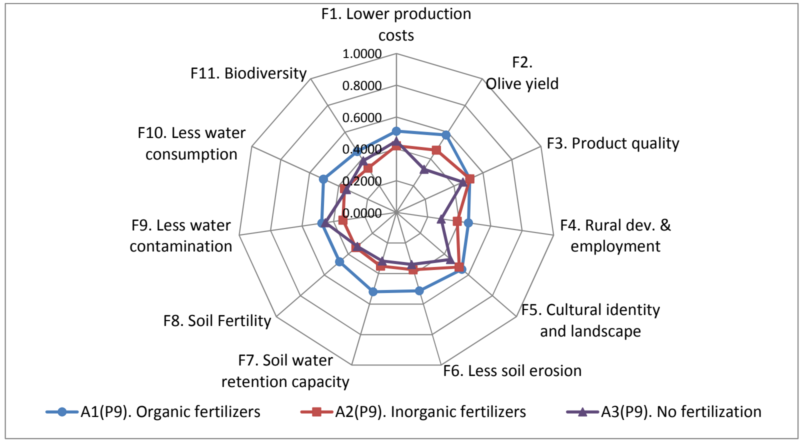
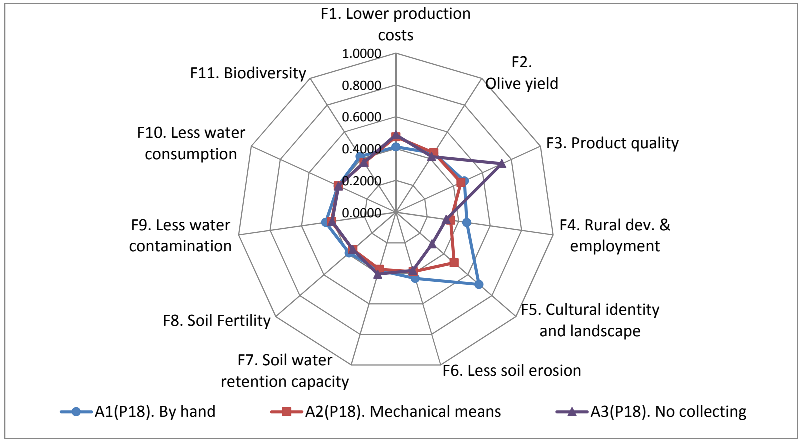


Figure 2. (Cont.)

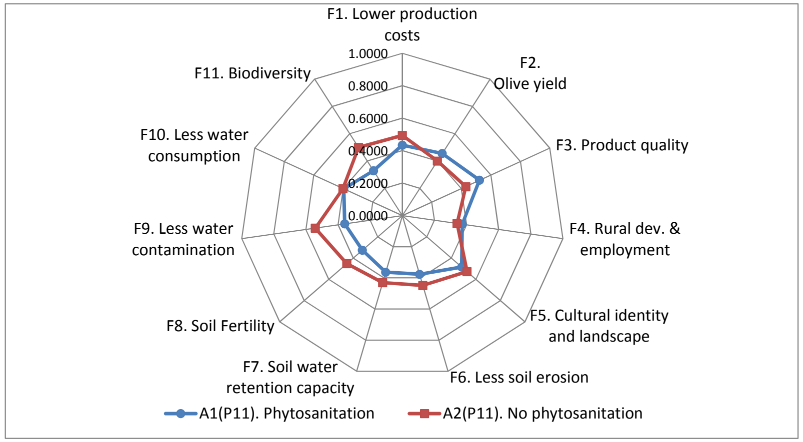
P9. Fertilizers used



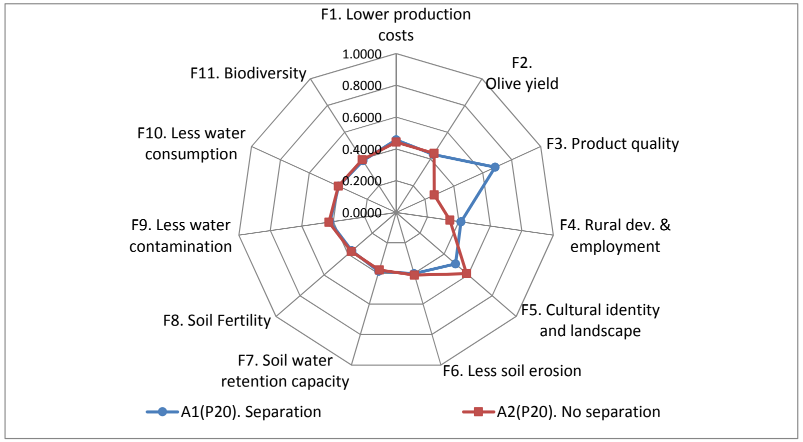
P18. Method for collecting the fallen olives from ground



P11. Phytosanitation



P20. Separation of the olives from ground and trees



Irrigating –P3– is also a highly sensitive farming practice (mean S index = 0.1153). Irrigating scores negative for less water consumption –F10– and lower production costs –F1–; in other words, it entails, logically, greater water consumption and costs. However irrigating is positive for olive yield –F2– (Figure 2.P3) and most of the remaining functions. Irrigation system and timing and water quality analysis –P4 to P6– appear not to be very sensitive and their impact on the multifunctional performance of olive growing is low. These results concur with the work of Gómez-Limón and Arriaza-Balmón (2011) and Gómez-Limón et al. (2011), who highlight the better performance of irrigated olive growing. Tognetti et al. (2008) emphasize the positive effect of irrigation on olive yield.

With the exception of soil or leaf analysis before fertilization –P10–, which scores neutral, the group of fertilization practices –GP4– is very sensitive and greatly affects the yield of the olive plantation –F2–, the social function of rural development and employment –F4–, and most of the environmental functions –F6 to F11– (Table 4). The effects of fertilization –P7– are in general positive with the logical exception of water contamination –F9– (Figure 2.P7). The fertilizers used –P9– are very sensitive, with the organic ones –A1(P9)– offering the best technical option especially from an environmental point of view (Figure 2.P9). Fertirrigation is the best application method –P8– for almost all the functions (Figure 2.P8). Previous works validate these results with regard to the influence of fertilization on economic and soil-related functions (Beltrán et al., 2005; Tabatabaei, 2006; Erel et al., 2008; Morales-Sillero et al., 2008; Restrepo-Diaz et al., 2008; Fernández-Escobar et al., 2009). The positive incidence of organic fertilizers on olive grove soil fertility is described by Beltrán et al. (2005). It is also worth noting that the group of harvesting practices –GP6– has a potentially relevant effect on product quality –F3– and the two social functions of olive growing: cultural identity and landscape –F5– and rural development and employment –F4– (Table 4). For example, not collecting the fallen olives from the ground –A3(P18)– and separating the olives collected from ground and trees –A1(P20)– both greatly benefit product quality –F3–. However, not collecting the fallen olives can negatively affect the function of cultural identity and landscape –F5– since this would be considered poor technique from a traditional perspective (Figure 2.P18).

Phytosanitation –P11– is also very sensitive since it has a great impact on farm-level multifunctional performance (Table 4). Applying phytosanitary treatments has a relevant positive impact on product quality –F3– and yield –F2– although it negatively affects production costs –F1– and all the environmental functions, especially those related to biodiversity, water contamination and soil properties (Figure 2.P11). However, neither the specific treatments implemented nor their timing and localization –P12 to P16– appear to have much impact on multifunctionality (Table 4).

3.2. Average and optimal farming techniques and their multifunctional performance

In this section, the current average farming techniques implemented by Andalusian olive growers and their performances will be compared with those techniques which are considered optimal in the diverse functions and their impacts for the average agro-climatic, environmental and socio-institutional conditions of olive cultivation in Andalusia. Furthermore, current average techniques will be compared with past average techniques -implemented 10 years ago- to analyse the evolution of multifunctionality over time. This temporal analysis assumes that technology did not evolve significantly in this period and that the technical alternatives available for growers are essentially the same. To determine the current average farming techniques for the year 2011, a survey of 400 olive farmers of the main olive oil producing zones –Jaen, Cordoba and Granada– was carried out from May 2010 to February 2011. The stratification of the survey was proportional to the number of olive farmers in five predefined major homogeneous olive growing zones, which include municipalities of a similar importance for olive cultivation (expressed in terms of olive surface area over total surface area). The survey was based on face-to-face interviews following a structured questionnaire. The average farming techniques currently implemented are defined by the modal answers in the survey, i.e. the most frequent technical alternative for each farming practice. The average techniques implemented in 2001 were also defined as the modal farming techniques for 2001 and were taken from a previous survey in the region (Parra-López and Calatrava-Requena, 2006). The optimal farming techniques, one optimal farming pack for each function, were defined according to the methodology presented in section 2.2.4. However, due to space limitations, we will especially focus on certain selected functions based on their importance for the region or growing sector. Moreover, we will specifically focus on the highly sensitive farming practices determined in the previous section, since they have the highest potential to affect the multifunctionality of olive growing. The farming techniques are summarized in Table 5 and the farm-level multifunctional performances associated with them in Figure 3.

Table 5. Current average, selected optimal and past average farming techniques

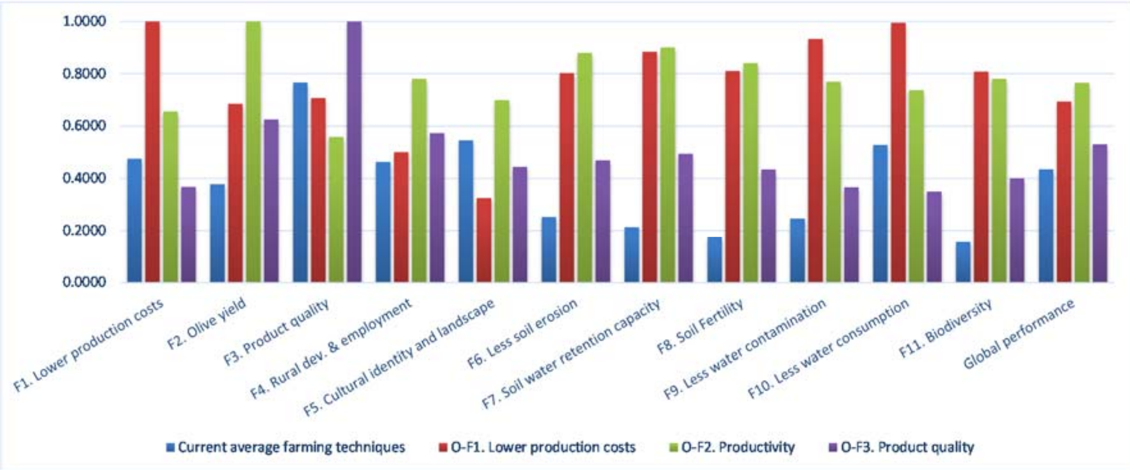
			Current average farming techniques (2011)	Optimal farming techniques				Past average farming techniques (2001)
				O-F1. Lower production costs	O-F3. Product quality	O-F4. Rural dev. & employment	O-F6. Less soil erosion	
GP1.Planting	**P1. Olive variety**		A1(P1). Picual	A4(P1). Lechín de Granada ●	A5(P1). Picudo ●	A1(P1). Picual	- Indifferent -	A1(P1). Picual
GP2. Soil management	**P2. Soil management**	(+)	A3(P2). Bare soil, little tillage or shallow tillage, weed control with herbicides	A4(P2). Soil covered by spontaneous or cultivated plants ●	- Indifferent -	A4(P2). Soil covered by spontaneous or cultivated plants ●	A4(P2). Soil covered by spontaneous or cultivated plants ●	A1(P2). Bare soil, conventional farming (constant tillage) ●
GP3. Irrigation	**P3. Irrigation**	(+)	A2(P3). No irrigation	A2(P3). No irrigation	A1(P3). Irrigation ●	A1(P3). Irrigation ●	A1(P3). Irrigation ●	A2(P3). No irrigation
	P4. Irrigation system		A4(P4). No irrigation	A4(P4). No irrigation	- Indifferent -	A1(P4). Trickle irrigation ●	A2(P4). Sprinkler irrigation ●	A4(P4). No irrigation
	P5. Timing of irrigation		A3(P5). No irrigation	A3(P5). No irrigation	A2(P5). Following expert advice (depending on crop needs) ●	A2(P5). Following expert advice (depending on crop needs) ●	- Indifferent -	A3(P5). No irrigation
	P6. Analysis of the quality of the irrigation water		A3(P6). No irrigation	A3(P6). No irrigation	A1(P6). Analysis of water ●	A1(P6). Analysis of water ●	A1(P6). Analysis of water ●	A3(P6). No irrigation
GP4. Fertilization	**P7. Fertilization**	(+)	A1(P7). Fertilization	A1(P7). Fertilization	A1(P7). Fertilization	A1(P7). Fertilization	A1(P7). Fertilization	A1(P7). Fertilization
	P8. Method for the application of fertilizers	(+)	A3(P8). Spray application to the leaves	A1(P8). Direct application to the soil ●	- Indifferent -	A2(P8). Fertilization through the irrigation water (fertirrigation) ●	A2(P8). Fertilization through the irrigation water (fertirrigation) ●	A1(P8). Direct application to the soil ●
	P9. Fertilizers used	(+)	A2(P9). Inorganic fertilizers	A1(P9). Organic fertilizers (including pruning remains, compost, etc.) ●	- Indifferent -	A1(P9). Organic fertilizers (including pruning remains, compost, etc.) ●	A1(P9). Organic fertilizers (including pruning remains, compost, etc.) ●	A2(P9). Inorganic fertilizers
	P10. Analysis of soil or leaf before fertilization		A2(P10). No analysis of soil/leaf	A1(P10). Analysis of soil/leaf ●	A1(P10). Analysis of soil/leaf ●	A1(P10). Analysis of soil/leaf ●	- Indifferent -	A2(P10). No analysis of soil/leaf
GP5. Phytosanitation	**P11. Phytosanitation**	(+)	A1(P11). Phytosanitation	A2(P11). No phytosanitation ●	A1(P11). Phytosanitation	A1(P11). Phytosanitation	A2(P11). No phytosanitation ●	A1(P11). Phytosanitation
	P12. Treatment of olive fruit fly (Bractrocera oleae)		A3(P12). Non-biological insecticide	A4(P12). No phytosanitation ●	A3(P12). Non-biological insecticide	A2(P12). Biological control (Opius concolor) ●	A4(P12). No phytosanitation ●	A1(P12). Mass traps (one trap per tree = pheromones + glue + pyrethroids) ●
	P13. Treatment of olive moth (Prays oleae)		A2(P13). Chemical treatments	A3(P13). No phytosanitation ●	A1(P13). Biological control (Bacillus thuringiensis) ●	A1(P13). Biological control (Bacillus thuringiensis) ●	A3(P13). No phytosanitation ●	A2(P13). Chemical treatments
	P14. Treatment of peacock spots (Spilocaea oleagina)		A2(P14). Copper fungicides	A4(P14). No phytosanitation ●	A1(P14). Pruning to clear ●	A1(P14). Pruning to clear ●	A4(P14). No phytosanitation ●	A2(P14). Copper fungicides
	P15. Timing of phytosanitary treatments		A1(P15). On a fixed calendar basis or with the first symptoms of infestation/infection	A3(P15). No phytosanitation ●	A2(P15). When the infestation/infection surpasses a threshold or following expert advice ●	A2(P15). When the infestation/infection surpasses a threshold or following expert advice ●	A3(P15). No phytosanitation ●	A1(P15). On a fixed calendar basis or with the first symptoms of infestation/infection
	P16. Localization of phytosanitary treatments		A1(P16). The whole plantation	A3(P16). No phytosanitation ●	- Indifferent -	A2(P16). Only the infestation/infection source ●	A3(P16). No phytosanitation ●	A1(P16). The whole plantation
GP6. Harvesting	**P17. Timing of harvest**		A1(P17). According to a fruit ripeness index	- Indifferent -	A1(P17). According to a fruit ripeness index	A1(P17). According to a fruit ripeness index	- Indifferent -	A1(P17). According to a fruit ripeness index
	P18. Method for collecting the fallen olives from the ground	(+)	A1(P18). By hand	A3(P18). No collecting ●	A3(P18). No collecting ●	A1(P18). By hand	A1(P18). By hand	A1(P18). By hand
	P19. Method for collecting the olives from the trees	(+)	A2(P19). Branch or trunk vibrators	A2(P19). Branch or trunk vibrators	A3(P19). Handpicking ●	A3(P19). Handpicking ●	A1(P19). Hand–pole beating ●	A1(P19). Hand–pole beating ●
	P20. Separation of the olives from ground and trees	(+)	A1(P20). Separation	A1(P20). Separation	A1(P20). Separation	A1(P20). Separation	- Indifferent -	A1(P20). Separation
	P21. Ways of carrying the olives from the olive grove to the mill		A3(P21). In the tractor or lorry trailer	A3(P21). In the tractor or lorry trailer	A2(P21). Boxes ●	A2(P21). Boxes ●	- Indifferent -	A3(P21). In the tractor or lorry trailer
GP7. Pruning	**P22. Pruning intensity**		A1(P22). Traditional, severe, every 1 or 2 years	A2(P22). Low intensity pruning, every 2 or 3 years ●	- Indifferent -	A1(P22). Traditional, severe, every 1 or 2 years	A2(P22). Low intensity pruning, every 2 or 3 years ●	A1(P22). Traditional, severe, every 1 or 2 years

(+) = Highly sensitive farming practices (see Table 4).

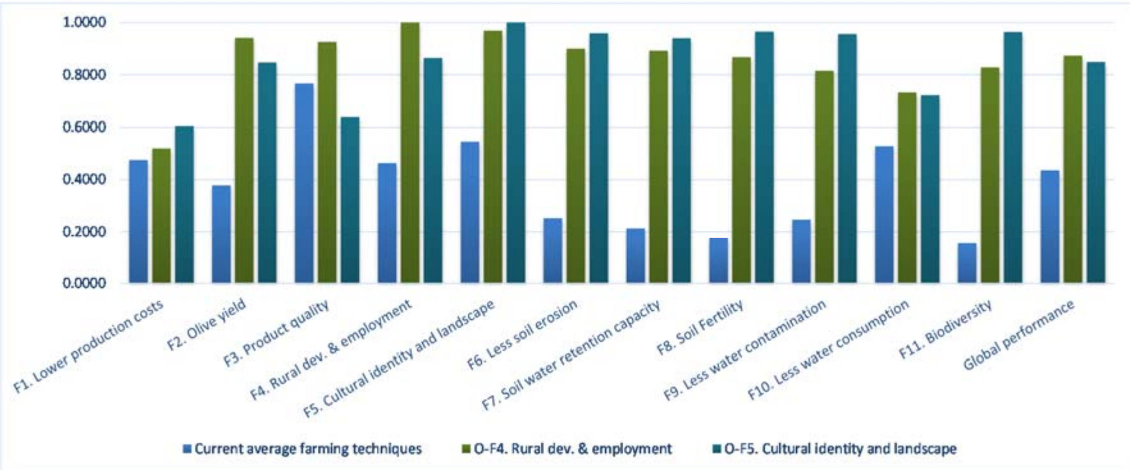
● *= Farming techniques different from the 'current average farming techniques'.*

Figure 3. Multifunctional performance associated with the average and optimal farming techniques. For a definition of multifunctional performance, average and optimal farming practices see sections 2.2.4 and 3.2, respectively.

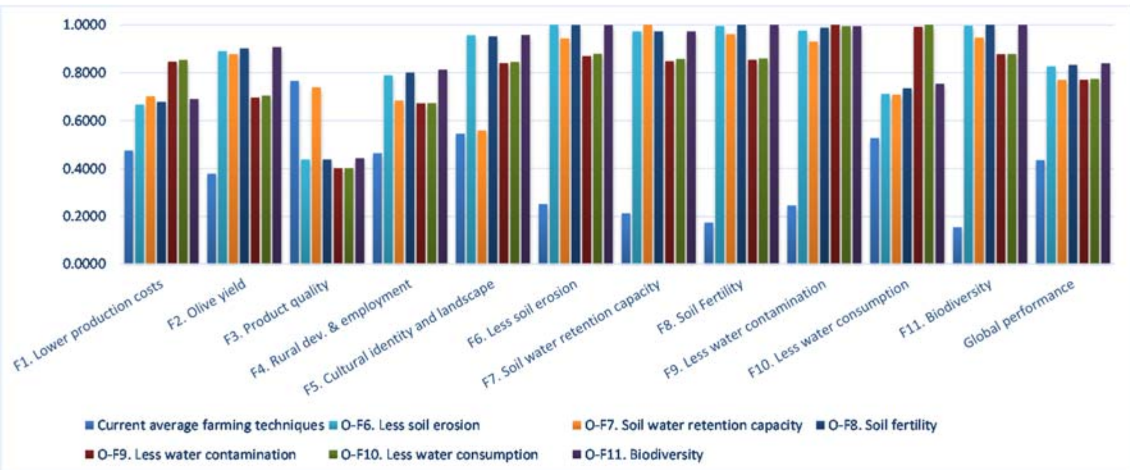
a) Economic optimums



b) Social optimums



c) Environmental optimums



The current average farming techniques for the highly sensitive farming practices are as follows: soil management through bare soil with little or shallow tillage; no irrigation; fertilization through spray application using inorganic fertilizers; use of phytosanitary treatments; collection of the fallen olives by hand; collecting the olives from trees with vibrators; separation of the olives from ground and trees (Table 5). The following points regarding the multifunctional performance associated with these current average farming techniques should be highlighted: 1) The only function that is relatively well accomplished with the current average farming techniques (performance of over 0.6000) is product quality –F3–, with a relative performance of almost 0.8000 (Figure 3, any of the 3 graphs), because it is not adversely affected by not using soil cover and due to the positive impact of phytosanitary treatments and separation of olives; 2) Other functions that are fairly well achieved (performance from 0.4000 to 0.6000) are the economic function of lower costs –F1–, the two social functions –F4 and F5–, and the environmental function of less water consumption –F10–; 3) The rest of the functions, including the remaining environmental functions and olive yield, are currently poorly achieved (performance below 0.4000); this is due to the combination of not using soil cover, not irrigating, carrying out phytosanitary treatments (which moreover are mostly chemical and intensive) and using inorganic fertilizers instead of organic ones.

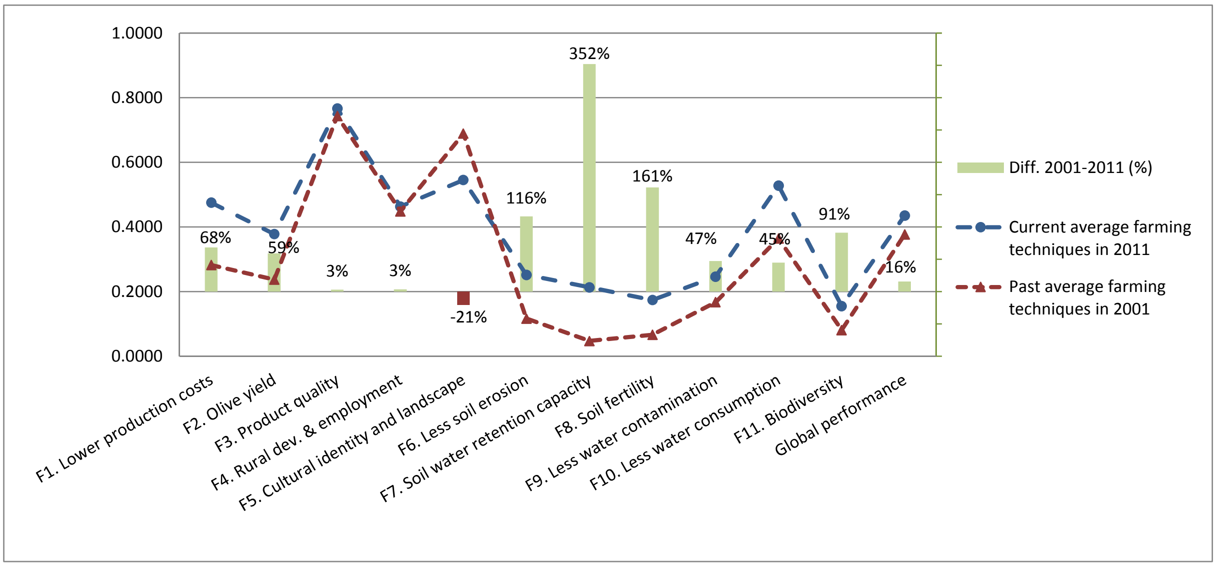
There is therefore much room for improvement in current farming techniques. Cost optimization is an important objective for farmers. The major changes needed to implement this pack, O-F1 'Lower production costs', setting out from the current situation, are as follows (Table 5): use of soil cover instead of bare soil, direct application of fertilizers to the soil instead of spraying the leaves, use of organic fertilizers instead of inorganic ones, no phytosanitation, and no collection of olives from the ground. The implementation of this optimal pack would produce a relatively high performance in the economic and environmental functions (Figure 3.a), over 0.6000 in most cases. The environmental functions are significantly improved due mainly to the use of soil cover, organic fertilizers and no phytosanitation. The use of soil cover, organic fertilizers and not collecting olives from the ground help to maximize the objective of low costs –F1–. However, not collecting olives from the ground can have a negative impact on cultural identity and landscape –F5–, since it is not traditionally implemented. Otherwise, we should stress that the average current practices are very close to - although in general below - the optimum for quality (Figure 3.a. O-F3). The required changes are (Table 5): irrigating, not collecting the olives from the ground instead of collecting them by hand, and handpicking olives from the trees instead of using vibrators. Handpicking the olives and irrigating entail higher costs, having a negative effect on function –F1–. Not collecting olives from the ground has a negative effect on cultural identity and landscape –F5–, and the same applies for irrigating on water consumption –F9–. The remaining functions will be slightly improved if this optimal pack is applied.

However, farming techniques today are far from being socially and environmentally optimal. The environmental functions are currently, on average, far from being fully achieved. The optimization of 'less soil erosion' –O-F6– would require these changes with respect to the current situation in the highly sensitive practices (Table 5): use of soil cover instead of bare soil, irrigation, fertirrigation instead of spraying leaves, use of organic fertilizers instead of inorganic ones, no phytosanitation, and hand-pole beating the olives from trees instead of using vibrators. The environmental functions seem to be highly correlated: if one of them is optimized, the rest also achieve very high performances, close to maximum performance levels (Figure 3.c). This relationship is especially notable for less soil erosion –F6–, soil fertility –F8– and biodiversity –F11–. Therefore if less soil erosion is maximized, as for the proposed optimal pack O-F6, high soil fertility and biodiversity are also achieved. The positive effects on the environmental functions are due to using soil cover, avoiding phytosanitary treatments, using organic fertilizers and irrigation and fertirrigation. On the other hand, the maximization of the environmental functions entails a reduction in olive quality –F3– due to the lack of phytosanitation, and lower costs performance –F1– due to the need for irrigation and hand-pole beating.

The optimal pack for maximizing the social function of rural development and employment –O-F4– seems to be one of the best optimal packs, since it achieves a relatively high performance (over 0.8000) in most of the functions (Figure 3.b). This optimal farming pack would entail these changes in the highly sensitive practices currently implemented (Table 5): use of soil cover instead of bare soil, irrigating, fertirrigation instead of spraying the leaves with fertilizers, use of organic fertilizers instead of inorganic ones, and not using machinery for collecting olives from the trees. An especially good performance was detected for O-F4 in the social functions due basically to soil cover, irrigation and the method of collecting olives from the trees, and in olive yield due to soil cover, irrigation and fertirrigation with organic fertilizers. On the other hand, the production costs for this optimum O-F4 are far from the best score (Figure 3.b) due to the handpicking of olives from the trees and irrigation, despite the improvement brought by the use of soil cover.

In spite of the non-optimal performance of the average farming techniques currently implemented in Andalusia - based on our data for 2011- the multifunctional performance of olive growing has significantly increased in a decade with respect to the figures for 2001: a 16% increase in global performance, taken as the average of the economic, social and environmental performances (Figure 4). The greatest improvements were in the economic functions of reducing costs –F1– and increasing olive yield –F2– and in the environmental functions –F6 to F11–. Product quality –F3– did not improve much further because its performance was already high in 2001. The social functions did not increase significantly. In fact, the cultural identity and landscape function –F5– was negatively affected because some new practices are somewhat in conflict with the olive growing tradition in the region. The main changes in this decade were (Table 5): soil management by conventional tillage changed to little/shallow tillage, which is less environmentally aggressive and costly and more productive; collecting olives from trees by hand-pole beating changed to mechanical means, which saves costs but is in conflict with the traditional concepts of olive growing; soil fertilization changed from applying directly to the soil to spraying the leaves, with little incidence in all the functions.

Figure 4. Multifunctional performance associated with average farming techniques: evolution 2001-2011. For a definition of multifunctional performance and average farming practices see sections 2.2.4 and 3.2, respectively.



3.3. Alternative farming packs and their multifunctional performance

Integrated Production (IP), Protected Designation of Origin (PDO) and intensive agriculture currently represent significant alternatives to the average farming pack, as previously indicated. The farming techniques associated with each alternative farming pack are defined, again, by the modal answers in the survey of Andalusian olive growers (Table 6). These practices and their multifunctional performances will be compared with the average farming techniques and their performances (Figure 5) for the average agro-climatic, environmental and socio-institutional conditions of olive cultivation in Andalusia. Due to the relatively low level of adoption of the alternative packs, average farming techniques correspond to those of the non-integrated (or conventional), non-intensive (or extensive) and non-PDO farming packs.

Table 6. Current average and alternative farming techniques

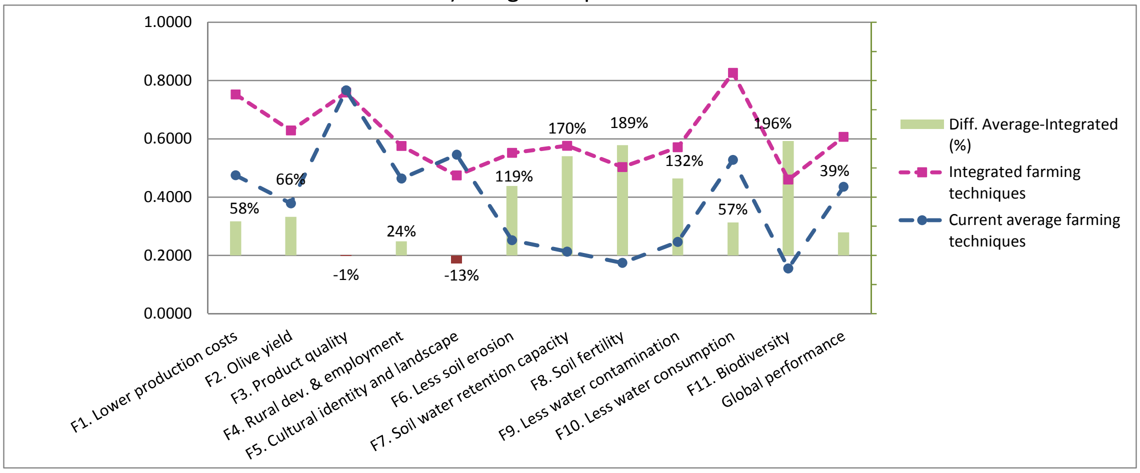
			Current average farming techniques	Integrated farming techniques	Intensive farming techniques	PDO farming techniques
GP1.Planting	**P1. Olive variety**		A1(P1). Picual	A1(P1). Picual	A1(P1). Picual	A1(P1). Picual
GP2. Soil management	**P2. Soil management**	(+)	A3(P2). Bare soil, little tillage or shallow tillage, weed control with herbicides	A4(P2). Soil covered by spontaneous or cultivated plants ●	A4(P2). Soil covered by spontaneous or cultivated plants ●	A3(P2). Bare soil, little tillage or shallow tillage, weed control with herbicides
GP3. Irrigation	**P3. Irrigation**	(+)	A2(P3). No irrigation	A2(P3). No irrigation	A1(P3). Irrigation ●	A2(P3). No irrigation
	P4. Irrigation system		A4(P4). No irrigation	A4(P4). No irrigation	A1(P4). Trickle irrigation ●	A4(P4). No irrigation
	P5. Timing of irrigation		A3(P5). No irrigation	A3(P5). No irrigation	A1(P5). On a fixed calendar basis (not depending on crop needs) ●	A3(P5). No irrigation
	P6. Analysis of the quality of the irrigation water		A3(P6). No irrigation	A3(P6). No irrigation	A2(P6). No analysis of water ●	A3(P6). No irrigation
GP4. Fertilization	**P7. Fertilization**	(+)	A1(P7). Fertilization	A1(P7). Fertilization	A1(P7). Fertilization	A1(P7). Fertilization
	P8. Method for the application of fertilizers	(+)	A3(P8). Spray application to the leaves	A1(P8). Direct application to the soil ●	A3(P8). Spray application to the leaves	A1(P8). Direct application to the soil ●
	P9. Fertilizers used	(+)	A2(P9). Inorganic fertilizers	A2(P9). Inorganic fertilizers	A2(P9). Inorganic fertilizers	A2(P9). Inorganic fertilizers
	P10. Analysis of soil or leaf before fertilization		A2(P10). No analysis of soil/leaf	A2(P10). No analysis of soil/leaf	A1(P10). Analysis of soil/leaf ●	A2(P10). No analysis of soil/leaf
GP5. Phytosanitation	**P11. Phytosanitation**	(+)	A1(P11). Phytosanitation	A1(P11). Phytosanitation	A1(P11). Phytosanitation	A1(P11). Phytosanitation
	P12. Treatment of olive fruit fly (Bractrocera oleae)		A3(P12). Non-biological insecticide	A3(P12). Non-biological insecticide	A3(P12). Non-biological insecticide	A3(P12). Non-biological insecticide
	P13. Treatment of olive moth (Prays oleae)		A2(P13). Chemical treatments	A2(P13). Chemical treatments	A2(P13). Chemical treatments	A2(P13). Chemical treatments
	P14. Treatment of peacock spots (Spilocaea oleagina)		A2(P14). Copper fungicides	A2(P14). Copper fungicides	A2(P14). Copper fungicides	A2(P14). Copper fungicides
	P15. Timing of phytosanitary treatments		A1(P15). On a fixed calendar basis or with the first symptoms of infestation/infection	A2(P15). When the infestation/infection surpasses a threshold or following expert advice ●	A1(P15). On a fixed calendar basis or with the first symptoms of infestation/infection	A1(P15). On a fixed calendar basis or with the first symptoms of infestation/infection
	P16. Localization of phytosanitary treatments		A1(P16). The whole plantation	A1(P16). The whole plantation	A1(P16). The whole plantation	A1(P16). The whole plantation
GP6. Harvesting	**P17. Timing of harvest**		A1(P17). According to a fruit ripeness index	A1(P17). According to a fruit ripeness index	A1(P17). According to a fruit ripeness index	A1(P17). According to a fruit ripeness index
	P18. Method for collecting the fallen olives from the ground	(+)	A1(P18). By hand	A2(P18). Mechanical means ●	A1(P18). By hand	A1(P18). By hand
	P19. Method for collecting the olives from the trees	(+)	A2(P19). Branch or trunk vibrators	A2(P19). Branch or trunk vibrators	A2(P19). Branch or trunk vibrators	A2(P19). Branch or trunk vibrators
	P20. Separation of the olives from ground and trees	(+)	A1(P20). Separation	A1(P20). Separation	A1(P20). Separation	A1(P20). Separation
	P21. Ways of carrying the olives from the olive grove to the mill		A3(P21). In the tractor or lorry trailer	A3(P21). In the tractor or lorry trailer	A3(P21). In the tractor or lorry trailer	A3(P21). In the tractor or lorry trailer
GP7. Pruning	**P22. Pruning intensity**		A1(P22). Traditional, severe, every 1 or 2 years	A1(P22). Traditional, severe, every 1 or 2 years	A1(P22). Traditional, severe, every 1 or 2 years	A1(P22). Traditional, severe, every 1 or 2 years

(+) = *Highly sensitive farming practices (see Table 4)*

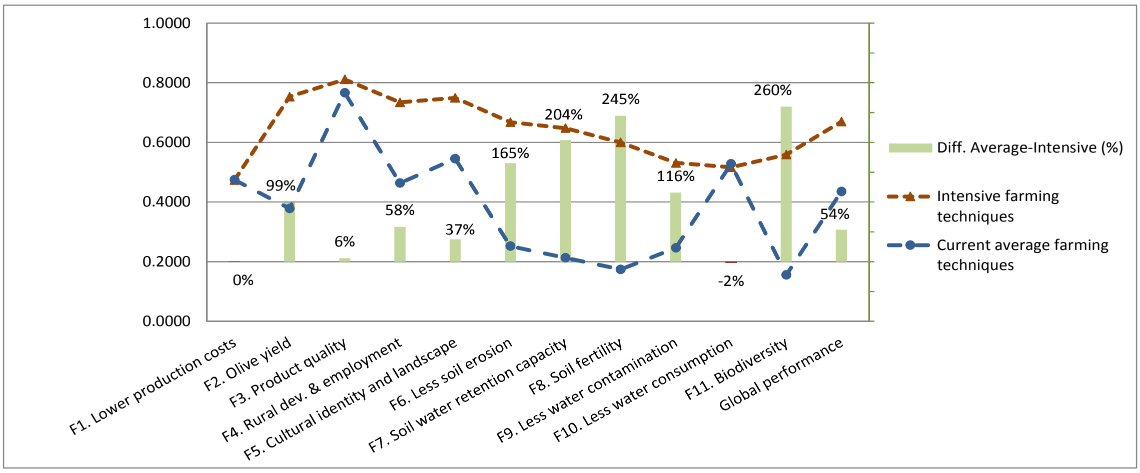
● = *Farming techniques different from the 'current average farming techniques'.*

Figure 5. Multifunctional performance associated with alternative farming packs. For a definition of multifunctional performance and alternative farming packs see sections 2.2.4 and 3.3, respectively.

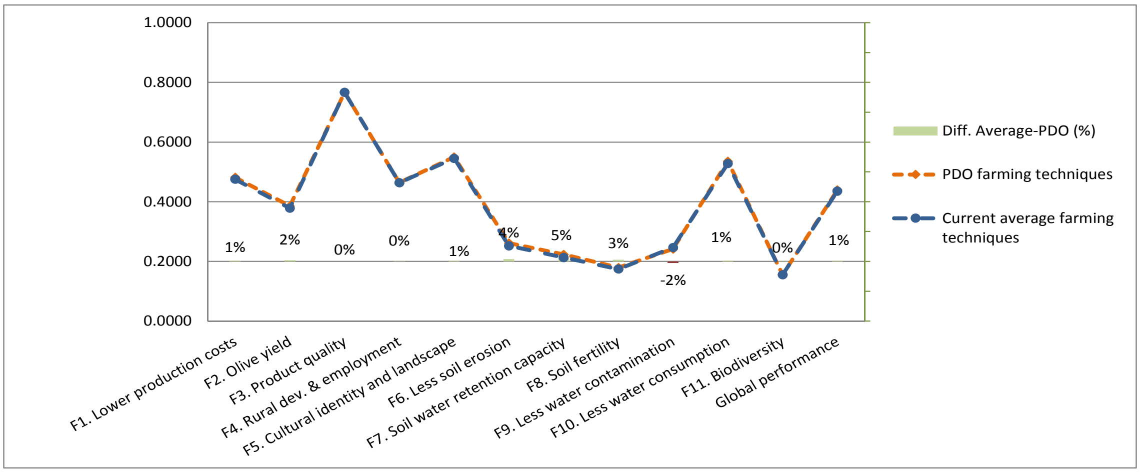
a) Integrated production



b) Intensive agriculture



c) Protected Designation of Origin



The differences between IP farming techniques and average techniques in the highly sensitive farming practices are the use of soil cover instead of little or shallow tillage, the direct application of fertilizers to the soil instead of spraying the leaves, and the collection of fallen olives by mechanical means instead of by hand (Table 6). IP achieves a much higher global performance; 39% higher, on average, than conventional agriculture (Figure 5.a). These results are in keeping with some previous studies (Parra-Lopez et al., 2007; Parra-López et al., 2008a). From an economic point of view, IP farmers appear to be more efficient: they are obtaining a product of similar quality to non-IP farmers, but their olive yield is greater (66% more) and their production costs are lower (58% less). This can be explained by the greater rationality of IP techniques, particularly soil management through the use of soil cover. In terms of social performance, IP contributes to a greater extent to rural development and employment (24% more than non-IP) but less to the enforcement of cultural identity and landscape (13% less). Many conflicting and indirect effects of the farming techniques on social functions may serve to explain this. For instance, the greater use of soil cover can strengthen the development of parallel activities in the countryside, such as agricultural tourism, since this kind of landscape is preferred by potential visitors (Sayadi et al., 2009). On the other hand, IP farmers' higher use of machinery can have a negative effect on cultural identity and landscape. The differences are more marked in environmental performance, especially in terms of biodiversity, soil fertility and soil water retention capacity (more than 170% in all cases), which may be related to the use of soil cover. Water scarcity and a decrease in biodiversity are some of the main environmental problems of many olive-growing areas in Spain and other Mediterranean countries (Beaufoy, 2001).

The farming techniques for the sensitive practices that differentiate intensive agriculture from average agriculture are the use of soil cover instead of little or shallow tillage and irrigation (Table 6), both of which have a very positive effect in almost all the functions, in agreement with previous studies (e.g. (Gómez-Limón et al., 2011). This translates into a 54% higher global performance than the average - i.e. non-intensive - farming techniques (Figure 5.b). Intensive agriculture substantially increases the olive yield (99%), although it achieves a similar economic performance in terms of product quality and a slightly worse performance (close to 0%) in terms of costs (Figure 5.b). Intensive agriculture is highly superior from an environmental perspective, with the logical exception of its poor performance in the lower water consumption function. It is also better in social terms, contributing to rural development and employment and to cultural identity and landscape. Finally, a few - generally positive - differences in performance were detected between PDO-certified and average (non-PDO) farms (Figure 5.c). PDO achieves a 1% higher global performance. This is because the only different farming technique applied by PDO farmers is the direct application of fertilizers to the soil instead of spraying the leaves (Table 6), which has little impact on the multiple functions of olive growing.

4. Discussion

An integrated approach is needed for evaluating MFA. ANP permitted such an integrated approach, thus allowing the proposed model to be: a) holistic, jointly incorporating a broad range of farming techniques and functions of agriculture, some of them underrepresented in the literature, especially those related to social, biotic and landscape topics, such as the analyzed functions of rural development and employment, cultural identity and landscape, and biodiversity; b) systemic, looking at agricultural production as a system made up of diverse elements, such as farming techniques and functions, interrelated through defined mechanistic patterns, in the form of network relationships defined by matrices, which allows predictions and simulations; c) integrative, incorporating information of a varied nature and different levels of complexity, such as hard data when available alongside expert-based qualitative, subjective and intangible ad-hoc information; and d) transdisciplinary, allowing communication between scientists from different disciplines, such as agronomy, ecology and economics, by means of a common problem-solving language based on mathematics; and communication with other stakeholders, such as managers, administrators and the general public, through a user-friendly language based on the synthesis of information. ANP increases transparency and objectivity in the assessment process, thus facilitating communication between stakeholders, and saves in costs and time by allowing for the use of a wide range of information sources. The practical implementation of ANP is facilitated by the software package Superdecisions (www.superdecisions.com) and certain practical guidelines (Saaty, 2003). These properties [the advantages previously cited] and facilities are useful in the evaluation of MFA and make ANP a potentially useful tool in this field. Apart from highlighting the strengths of ANP and the proposed model, some weaknesses also need to be considered. With regard to ANP, a heated debate is apparent in the literature on certain axioms and principles of AHP, the origin of ANP. Most of this criticism comes from the traditional areas of Decision Theory and is related to the independence and relevance of objectives, qualitative comparisons, the representativeness of judgements, and the open/closed nature of the model. Interested readers are referred to Parra-López et al. (2008b). This debate, which is normal and indeed desirable in science, does not discredit ANP but nonetheless requires mention for a clear understanding and qualification of the methods used. Moreover, the proposed model entails some simplifications and assumptions, as for any model. For instance, climate change was not analyzed due to the lack of previous information and knowledge on olive growing. This remains pending for future research.

The modelling process followed a mechanistic agro-ecological engineering approach (Ittersum and Rabbinge, 1997; Parra-López et al., 2008c). This assumes that the multifunctional - economic, environmental and social - performance/outputs of an agricultural system at farm-level for a given crop and agronomic, socio-economic and environmental context are fully determined by the farming techniques/inputs used. This approach is essentially different from the classical 'empirical' econometric approaches in which input-output combinations and production functions are based on practice, statistics or extrapolations for certain very restrictive conditions (Ittersum and Rabbinge, 1997), making it difficult to deal with specific alternative technological options or new constraints and policies (Janssen and van Ittersum, 2007). In contrast, ANP permits a mechanistic approach in which models are built on existing theory and knowledge of farm processes, making long-term predictions and simulations of new behavior possible outside the range of observed data (Janssen and van Ittersum, 2007).

The validity of our model and results was evaluated through a-posteriori contrast with the abundant previous literature on the impacts of farming techniques on the functions of olive growing, as detailed previously. These studies are in general narrowly focused on a few practices and impacts, but some of them are more holistic, such as those analyzing the multifunctionality of integrated production. In any case, the model was specified for the average agro-climatic, environmental and socio-institutional conditions of olive cultivation in Andalusia. However, the sector is heterogeneous in terms of the structural characteristics of olive farms, the socio-economic framework, climate, etc. In other conditions, the results may change and would need to be further investigated, such as in the case of traditional mountain olive growing.

5. Conclusions

This paper aims to contribute to the field of farm-level modelling and evaluation of the multifunctionality of agriculture (MFA) by developing and applying an integrated model for the evaluation of the multiple functions of alternative farming techniques in olive growing in Andalusia. The modelling process was based on the methodological framework of ANP (Analytic Network Process), a Multi-Criteria Decision Analysis technique. ANP permitted an integrated - i.e. holistic, systemic, integrative and transdisciplinary - approach to evaluating and modelling MFA, dealing with complexity, uncertainty and risk. It allowed mechanistic modelling and dealt with multiple criteria and stakeholders, and the incorporation of qualitative, subjective and intangible information into the modelling process, in the form of expert knowledge, as well as quantitative and hard-data information. The modelling results indicate that, despite the positive evolution over the last decade, there is still much room for improvement in the farming techniques implemented in the Andalusian olive growing sector. Growers, as land managers, are applying farming techniques which are optimal for obtaining a high quality product, but to a certain extent they are neglecting the social impacts and, to an even greater extent, the environmental impacts of these techniques. The changes needed for the most sensitive farming practices are: using soil cover instead of bare soil, irrigating, fertirrigation instead of spraying the leaves with fertilizers and using organic fertilizers instead of inorganic ones. Furthermore, some specific optimal farming packs identified make it clear that an improved economic performance is not incompatible with social objectives, such as rural development and employment, and with the environmental protection of soil, water and biodiversity. In fact, agricultural policies favouring rural development may indirectly be reinforcing the diffusion of a multifunctional agriculture. The results also highlight the higher multifunctional performance of integrated production due to the application of more rational farming techniques, especially from an environmental point of view, and of intensive agriculture, which promotes the use of irrigation and soil cover. This study is a first step in a wider research project focused on the design of policies and strategies to promote the diffusion in Andalusia of the farming techniques with the highest potential to increase the competitiveness and sustainability of olive growing. This will require further analysis of the market and non-market benefits and costs for all the agents involved in the production and consumption of olive oil, such as olive growers, consumers, public administration and society in general. Persuading farmers to change current farming techniques entails the provision of appropriate and relevant information highlighting the importance and benefits of multifunctionality of agriculture in the medium to long term. In this context, the knowledge transfer role of public R&D institutions, technological centers and universities is essential. The proposed model should also be further refined and adapted to a wider range of agro-climatic, environmental and socio-institutional conditions present in Andalusia.

Acknowledgments

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Artículo 2.

A public/private benefits framework for the design of polices oriented to sustainability in olive growing

[Un marco de beneficios públicos/privados para el diseño de políticas orientadas a la sostenibilidad en la producción olivarera]

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Abstract

This paper contributes to the theory and practice of sustainability and welfare-optimizing management and policy by developing an integrated methodological framework for the design of public polices promoting sustainable farming techniques based on private/public net benefits. The framework, specified for the case of olive growing in Andalusia, Spain, combines two multi-criteria Analytic Network Process models of the multiple functions of olive growing with an economic analysis and a public/private benefits framework for cost-effective policy design. The benefits and costs of relevant stakeholders are considered: olive growers, olive oil consumers, public administrations and society in general. 400 olive growers, 27 experts in olive systems and 409 citizens were interviewed. The results show that techniques such as soil cover, organic fertilization, analysis of soil or leaf before fertilization, analysis of the quality of the irrigation water, fertirrigation, irrigating following expert advice and low intensity pruning should be targeted by public policies promoting sustainability. The policy mechanism revealed as the most cost-effective is extension, i.e. technology transfer, education, communication, demonstrations, and support for community networks. Territorial contracts and agri-environment schemes may also prove useful. The results also demonstrate that maximizing sustainability is not incompatible with improving the private net benefits of olive growers.

Keywords: Sustainability; policy evaluation and design; multifunctionality; good farming practices; Analytic Network Process (ANP); olive growing.

Highlights: ► An integrated framework for policy design oriented to olive sustainability is proposed; ► Multiple functions of agriculture, stakeholders, and benefits/costs are considered; ► Soil management, fertilization, irrigation and pruning practices must be addressed; ► Extension, agri-environment schemes and territorial contracts should be explored; ► Sustainability is not incompatible with private benefits for olive growers.

1. Introduction

The EU is promoting sustainable agriculture. The new Common Agricultural Policy (CAP) aims for a further greening of agriculture for 2014-2020 and the fulfilment of the environmental objectives of agricultural policy in a more cost-effective manner (Hodge, 2013). Sustainability, understood in a weak sense (Dietz and Neumayer, 2007; Martinez-Alier et al., 1998), implies that market net benefits for farmers (private net benefits), associated with the economic functions of agriculture, must be balanced against market and non-market net benefits, associated with the environmental and social functions of agriculture, for other agents such as consumers, public administrations and society in general (public net benefits). This balance determines the social net benefits of farming which may be interpreted as a measure of its sustainability (Parra-López et al., 2008b; Parra-López et al., 2009). The olive sector plays an important multifunctional role in Andalusia, the most important olive growing region in the world (Parra-López et al., 2008a). It is one of the main economic activities in many areas with an important social component as a job generator, especially in less privileged areas (Arriaza et al., 2007; Duarte et al., 2008; Fleskens et al., 2009). Its wide territorial presence causes olive growing to have a potentially high environmental impact (Parra-López et al., 2007). Therefore the design of public policies promoting a change towards more sustainable olive farming techniques is a topic of high priority.

Given the importance of promoting sustainability in practice, a sound conceptual framework must provide the means by which progress towards the ideal can be tracked, distinguishing sustainable actions and policies from unsustainable ones, while grounding the ideal itself in a defensible normative foundation (Vanderheiden, 2008). It has been suggested from within the field of Ecological Economics that a wide and integrated approach, non-necessarily monetary, combining economic valuation, integrated modelling, stakeholder analysis, and multi-criteria evaluation may provide complementary and new insights into sustainability and welfare-optimizing management and policy (Turner et al., 2000). A number of approaches are available for evaluating the multiple functions (economic, environmental and social) of agriculture. They are mainly farm-level bio-economic modelling techniques mostly based on mathematical programming or optimization models (Janssen and van Ittersum, 2007; Rossing et al., 2007; Zander et al., 2008). Although sustainability evaluation requires a holistic framework (Fleskens et al., 2009), most approaches do not specifically target a joint integrated evaluation of these multiple functions (Rossing et al., 2007).

Furthermore, incorporating all stakeholders and, specifically, public preferences into the sustainability analysis is important for the development of instruments that target potential public support (Hall et al., 2004). Efforts to incorporate societal demands usually spring from Environmental Economics using stated-preference techniques for monetary valuation. Multiple Criteria Decision

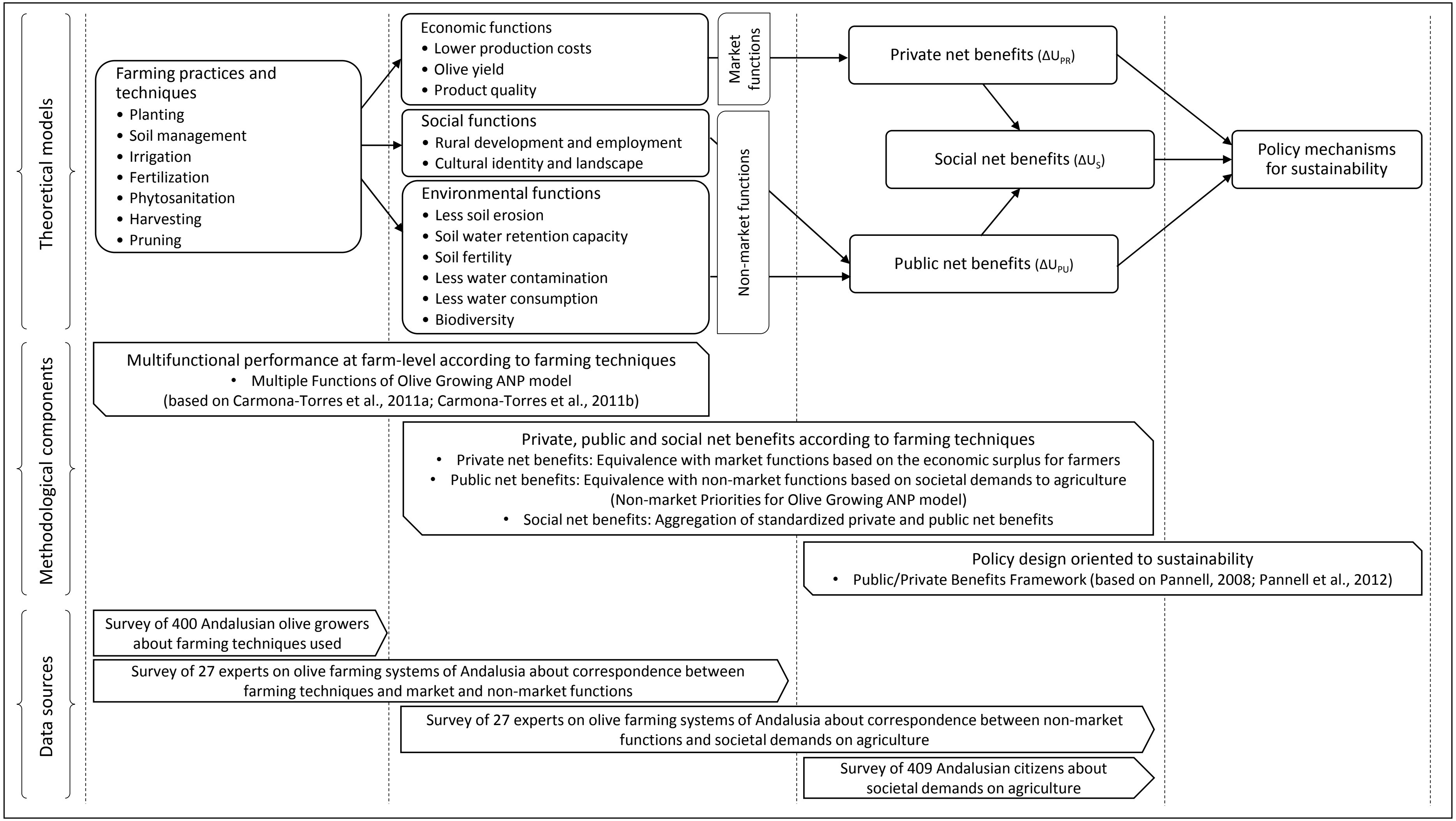
Analysis – MCDA (Figueira et al., 2005) is an alternative set of non-monetary techniques which are commonly used in environmental decision-making when multiple criteria must be evaluated and diverse stakeholders are involved (Hernández and Cardells, 1999; Parra-López et al., 2008a). In particular, the Analytic Network Process – ANP (Saaty, 2001) is a discrete MCDA method that allows the incorporation of qualitative, subjective and intangible information into the evaluation process, for instance in the form of expert knowledge, as well as quantitative and hard-data information when available. ANP has been used to assess societal preferences for non-market functions of dairy agro-landscapes and to design policies towards sustainability in the northern Netherlands (Parra-López et al., 2008b). In the particular case of olive growing, although there are several studies on societal demands for multifunctionality and non-market functions in Andalusia (Arriaza et al., 2007; Kallas et al., 2008; Kallas et al., 2006; Rodríguez-Entrena et al., 2012; Rodríguez-Entrena et al., 2014), they are essentially based on the Choice Experiment method and focus on particular agricultural conditions, especially extensive and mountain olive groves. More in line with our approach, ANP has been used for prioritizing the non-market functions linked to Protected Designation of Origin (PDO) olive oil (Pérez-y-Pérez et al., 2013) and irrigated olive groves in Andalusia (Villanueva et al., 2014). However, these studies do not explicitly isolate the contribution of each farming technique to multifunctionality and sustainability and do not incorporate societal demands. Carmona-Torres et al. (2011) and Carmona-Torres et al. (2014), on the other hand, used ANP as a modelling tool for the multifunctional performance of olive growing at farm-level according to the farming techniques implemented by olive farmers in Andalusia. This model, referred to as the Multiple Functions of Olive Growing ANP model from here on in, has been used and extended further here.

With all this in mind, the first objective of this paper is to develop an integrated methodological framework for the evaluation and design of agri-environmental public polices for sustainable olive growing at farm-level in Andalusia. This framework, which will be illustrated in the Material and methods section, consists of three consecutive and linked methodological components: i) Multifunctional performance at farm-level according to farming techniques, based on the Multiple Functions of Olive Growing ANP model (Carmona-Torres et al., 2014; Carmona-Torres et al., 2011), which will be summarised; ii) Private, public and social net benefits according to farming techniques, based on an economic analysis of private benefits and the prioritization of public benefits through a Non-market Priorities for Olive Growing ANP model defined *ad hoc*; and iii) Policy design oriented to sustainability, theoretically based on a Public/Private Benefits Framework (Pannell, 2008; Pannell et al., 2012), which allows the integration of the public and private benefits of growing and the design of cost-effective public policies; this is applied for the first time to olive growing. The second objective of the paper is to apply the proposed framework to improving the design of policies oriented to sustainability in Andalusian olive growing and promoting a change towards more sustainable farming techniques. Hence, certain relevant issues for policy design will be investigated in the Results section: 1) Prioritizing the non-market functions of olive growing according to societal demands on agriculture; 2) Determining the most improvable farming practices, i.e. those with the highest potential to improve sustainability, and the most sustainable farming techniques, i.e. the best technical alternative for each practice; 3) Analyzing the net benefits associated with the practices currently implemented by farmers and determining the appropriate policy mechanisms to promote a change towards the most sustainable farming techniques. The paper continues with a discussion of the proposed framework and main results.

2. Material and methods

A general overview of the proposed methodological framework is shown in Figure 1. It consists of three methodological components anchored on diverse theoretical models and fed by different data sources, which will be described in subsections 2.2 to 2.4. First, some basic characteristics of the study setting are provided in subsection 2.1.

Figure 1. The integrated public/private benefits methodological framework proposed



2.1. Study setting: Olive growing in Andalusia

Olive growing constitutes an important economic activity in Mediterranean countries, especially in Spain, which represented 25.4% of the world's total olive surface area and 33.4% of total production in the period 2005-10 (FAO, 2012; MAGRAMA, 2013; MARM, 2010). Andalusia, located in the south of Spain, is the most important olive growing region in the world. It represented 61.3% of the olive surface area and 82.2% of olive production in Spain in the period 2007-2010 (CAP, 2013). Olive growing plays an important socio-economic role in the region, providing 27.7% of Andalusian fruit and vegetable production in 2010 (CAP, 2012), and generating around one third of agricultural employment, 47.1% of which is family-based (CAP, 2009). Moreover, olive growing has a high potential to impact the environment in the region due to its wide territorial presence, covering 31.94% of the Andalusian agricultural area (MARM, 2010). Most of the olive crop is cultivated in a traditional extensive manner although an increasing surface area, around 17%, is cultivated more intensively with a massive use of productive inputs (Hinojosa-Rodríguez et al., 2014). The modal olive farm in Andalusia has these structural characteristics: Total farm area, 1-5 ha; type of cultivation, traditional; yield, 4000-6000 kg olives/ha; age of the olive plantation, 10-50 years; labour, family and temporary employees; destination of the product, olive oil; land slope, low; inserted cultivations, no; livestock management, no; main customer, first degree cooperative mills; main customer base location, Andalusia (Hinojosa-Rodríguez et al., 2014).

2.2. Multifunctional performance at farm-level according to farming techniques

This methodological component, which corresponds to columns 1 and 2 of Figure 1, is based on the Multiple Functions of Olive Growing ANP model (Carmona-Torres et al., 2014; Carmona-Torres et al., 2011). This model allows the evaluation of the multifunctional performance of olive growing at farm-level for the average agro-climatic, environmental and socio-institutional conditions of olive cultivation in Andalusia.

A model is schematized in ANP as a network of elements and clusters of elements, where every element can have an influence on itself or on some or all of the other elements of the system (Niemira and Saaty, 2004). This model consists of: 1) *Cluster of Functions* (C_F), which contains 11 relevant farm-level functions of agriculture of which 3 are market functions (FM), such as lower production costs, and 8 are non-market functions (FNM), such as rural development and employment; 2) *Cluster of Practices* (C_P), which consists of 22 olive farming practices, referring to 7 main groups of practices in olive growing ranging from planting to pruning; and 3) *Cluster of Alternatives* (C_A), which consists of the technical alternatives for each farming practice of the previous cluster. For instance, for farming practice P1 'olive variety', there are 5 technical alternatives, ranging from A1(P1) 'Picual' to A5(P1) 'Picudo'. A farming technique would be the use of the technical alternative 'Picual' for the farming practice 'olive variety'. The performance of an alternative farming pack A, i.e. a set of farming techniques, ranges from 0 to 1 in each function ($0 \leq p_{FMf(A)} \leq 1$ and $0 \leq p_{FNMf(A)} \leq 1$, for all market and non-market functions f, respectively). The maximum performance for each function can be achieved by implementing the optimal farming techniques for each farming practice that constitute a technically feasible combination. For instance, for function FM1 'lower production costs', the optimal farming techniques would be Lechín de Granada variety -A4(P1)-, soil cover -A4(P2)-, ... and low intensity pruning -A2(P22)-. In this way, 11 optimal farming packs can be defined, one for each function.

All changes in multifunctional performance are measured with respect to the modal farming pack, that is, the most frequent set of farming techniques. Determining the modal farming techniques required a survey of 400 olive farmers of the main olive oil producing zones of Andalusia –Jaen, Cordoba and Granada– which was carried out from 2010 to 2011. The correspondence between farming techniques and functions of olive growing was based on a survey of 27 experts on olive farming systems of Andalusia. For details see Carmona-Torres et al. (2011) and Carmona-Torres et al. (2014).

2.3. Private, public and social net benefits according to farming techniques

This methodological component corresponds to columns 2 and 3 of Figure 1.

2.3.1. Definition of private, public and social net benefits

In the Public/Private Benefits Framework (Pannell, 2008; Pannell et al., 2012), private net benefits (ΔU_{PR}) are the market net benefits for farmers. Market net benefits are defined as the change in utility for agents involved in the supply or demand of a marketable product/service. Utility is assumed to be equivalent to the neoclassical concept of surplus and is measured in monetary units. Therefore, market net benefits for farmers are defined as the change in surplus of farmers, i.e. change in gross margin (ΔGM). It is supposed that farmers' decisions about farming techniques to be implemented are made in a short enough term that fixed costs can be deemed constant. In this short term, prices of inputs and outputs are also assumed to be constant. In this situation, a change in GM is equivalent to a change in their profit as producers, profit being equal to gross margin minus fixed costs. Therefore, it can be stated that:

$$\Delta U_{PR(A)} = \Delta GM_{(A)} = \Delta[R - VC + S]_{(A)} = \Delta[(Y * P) - VC + S]_{(A)}$$

where $\Delta U_{PR(A)}$ are the private net benefits for farmers (€ ha^{-1}) associated with a change in farming practices from the modal farming pack to alternative farming pack *A*, *GM* is gross margin (€ ha^{-1}), *R* is market revenue (€ ha^{-1}), *VC* is variable costs (€ ha^{-1}), *S* is subsidies (€ ha^{-1}), *Y* is olive yield (kg olives ha^{-1}), and *P* is the price of the olives (€ kg $olives^{-1}$). We propose a linear relationship between the GM components and performances in the market functions (FM1 to FM3) defined in the Multiple Functions of Olive Growing ANP model (Carmona-Torres et al., 2014; Carmona-Torres et al., 2011) by considering the correspondence between their limits (Table 1). For instance, maximum olive yield (Y_{max}) is related to a performance of 1 in market function 2 ($p_{FM2(A)}$) (olive yield) and minimum olive yield (Y_{min}) is related to a performance of 0 in this function. Otherwise, the super-intensive olive grove has the maximum VC and Y and, at the other extreme, the non-machinable traditional grove has the minimum VC and Y. VC and Y for these cases were obtained from Penco Valenzuela and Cubero Navarro (2012). VC is inversely related to FM1 'lower production costs'. The price of the olives is directly related to their quality (FM3), the maximum P being for olives destined to 'extra-virgin' olive oil and the minimum P for olives destined to 'lampante' olive oil, which have to be refined and mixed before sale. The P for these two extreme olive categories was obtained from CAPMA (2013); MAGRAMA (2013) by assuming an average fat yield of 20% in Andalusia (Penco Valenzuela and Cubero Navarro, 2012). Finally, the subsidies are fixed and linked to historical yield. The average subsidies for Andalusian olive groves were calculated from (MAGRAMA, 2013); Penco Valenzuela and Cubero Navarro (2012). The equation defined for each component is shown in the last column of Table 1.

Table 1. Gross margin components according to performance in economic functions

Gross margin component		**Performance in economic function**		**Defined equation**
Component	Limits	Function	Limits	
Y (olive yield) [kg olives ha^{-1}]	Y_{max} = 10000	FM2. Olive yield	$p_{FM2(A)}$= 1	$Y = Y_{min}+(Y_{max}-Y_{min})*p_{FM2(A)} = 1750+8250*p_{FM2(A)}$
	Y_{min} = 1750		$p_{FM2(A)}$= 0	
P (price) [€ kg $olives^{-1}$]	P_{max} = 0.41646	FM3. Product quality	$p_{FM3(A)}$= 1	$P = P_{min}+(P_{max}-P_{min})*p_{FM3(A)} = 0.37400+0.04247*p_{FM3(A)}$
	P_{min} = 0.37400		$p_{FM3(A)}$= 0	
VC (variable costs) [€ ha^{-1}]	C_{max} = 2468.8	FM1. Lower production costs	$p_{FM1(A)}$= 0	$VC = VC_{max}-(VC_{max}-VC_{min})*p_{FM1(A)} = 2468.8-1392.6*p_{FM1(A)}$
	C_{min} = 1076.2		$p_{FM1(A)}$= 1	
S (subsidies) [€ ha^{-1}]	-	-		S = 826.44

$p_{FNMf(A)}$ = Performance in economic function f of a given alternative farming pack A

The term public net benefits (ΔU_{PU}) comprises market net benefits for agents other than farmers involved in the olive supply and demand market, measured in monetary units, and non-market net benefits for society in general, which lack a direct monetary value. It consists of three components in our case:

- Market net benefit for consumers: An approximation of the surplus of consumers for small changes in supply at constant demand curve is (P2-P1)*(Q2+Q1)/2, where *1* and *2* indicate two points of equilibrium, and *P* and *Q* indicate the price and the quantity of the product in the market respectively. Since in our model the price of the output (olives) is assumed to be constant, i.e. it is not affected by a change in the supply, market net benefit for consumers equals zero in our case.
- Market net benefit for public administrations: Utility for administrations increases if support for agriculture decreases. Since subsidies are not coupled to production in olive growing, they are constant. Therefore, market net benefit for public administrations is zero in our case.
- Non-market net benefits for society: These are associated with the impacts of changes in the multiple non-market functions of agriculture on the utility of society. In our case, we define a change in the utility of society as:

$$\Delta U_{NM(A)} = \sum_{f=1}^{FNM} \omega_{FNMf} * \frac{(p_{FNMf(A)} - p_{FNMf(M)})}{p_{FNMf(M)}}$$

where $\Delta U_{NM(A)}$ is the non-market net benefits for society, *FNM* is the number of non-market functions, ω_{FNMf} is the weight or priority of the non-market function *f* according to society, $p_{FNMf(A)}$ is the performance in non-market function f of alternative farming pack *A*, and $p_{FMNf(M)}$ is the performance in non-market function f of the modal farming pack *(M)*. In our case, non-market functions include social and environmental functions.

The weights of the non-market functions of olive growing (vector $\boldsymbol{\omega}_{\mathbf{FNM}}$) were calculated by defining a Non-market Priorities for Olive Growing ANP model, relating non-market functions of olive growing and societal demands on agriculture (Table 2). The model consists of: 1) *Cluster of non-market functions of olive growing* (C_{FNM}), which contains the 8 non-market functions of olive growing (FNM1 to FNM8) defined in the Multiple Functions of Olive Growing ANP model (Carmona-Torres et al., 2014; Carmona-Torres et al., 2011); 2) *Cluster of demands of society on agriculture* (C_D), which consists of 8 societal demands on agriculture (such as maintaining and generating employment); and 3) *Cluster of prioritization of non-market functions of olive growing* (C_{PNM}), which covers the priorities of the 8 non-market functions. The relationships between the elements of an ANP model can be mathematically represented as a supermatrix (Table 2). According to this model, the weights of the non-market functions are:

$$\mathbf{W_{FNM}} = \mathbf{W_{FNM,D}}.\mathbf{W_{D,D}}.\mathbf{W_{D,PNM}}$$

where $\mathbf{W_{FNM,D}}$ is a matrix that represents how non-market functions of olive growing satisfy societal demands on agriculture (e.g. rural development and employment may contribute to maintain and generate employment); $\mathbf{W_{D,D}}$ is a matrix that expresses the inner relationships between societal demands, since satisfying a societal demand may indirectly contribute to achieve other demands (e.g. maintaining and generating employment may contribute to maintaining and and recovering rural population); and $\mathbf{W}_{\mathbf{D,PNM}}$ is a column vector that represents weights of societal demands on agriculture. $\mathbf{W}_{\mathbf{FNM,D}}$ and $\mathbf{W}_{\mathbf{D,D}}$ were elicited in a survey of 27 experts on the olive farming systems of Andalusia, who were interviewed individually in 2010. Their fields of specialization were the olive sector (8 experts), agricultural economics (7), olive soil management (4), olive pests and diseases (3), olive growing (2), fertilization (1), olive quality (1) and organic olive production (1). Listed by profession, 16 were researchers from public research centres, 5 were practitioners of the olive growing sector, 3 were researchers from universities and 3 were government employees. The specification of these matrices was based on direct rating assessment (Bottomley and Doyle, 2001; Forman and Selly, 2001; Larichev et al., 1995): the influence of one element on another was directly elicited using a rating scale, ranging from 1 (very weak relationship) to 9 (very strong relationship), similar to that of Parra-López et al. (2008b). 0 is reserved for no relationship. For instance, the incidence of the non-market function FNM1 'rural development and employment' on societal demand D1 'producing healthy, safe and quality food' (an element of matrix $\mathbf{W}_{\mathbf{FNM,D}}$) could be assessed as 3 by one expert. Subsequently the individual matrices from experts were aggregated as the arithmetic mean of the individual matrices to obtain two aggregated submatrices, $\mathbf{W}_{\mathbf{FNM,D}}$ and $\mathbf{W}_{\mathbf{D,D}}$. Societal demands on agriculture ($\mathbf{W}_{\mathbf{D,PNM}}$) were directly assigned from a survey of Andalusian citizens conducted in 2010. This was based on a stratified sample of 409 citizens who were interviewed face to face following a structured questionnaire about their knowledge of the Common Agriculture Policy and demands on agriculture. The sampling error at 95% confidence level is 2.91% for extreme proportions and 4.85% for intermediate proportions.

Table 2. Supermatrix of the Non-market Priorities for Olive Growing ANP model

a) Supermatrix at cluster level

	C_{PNM}: Prioritization of non-market functions of olive growing	C_D: Demands of society on agriculture
C_{PNM}: Prioritization of non-market functions of olive growing	**I**	0
C_D: Demands of society on agriculture	$\mathbf{W}_{\mathbf{D,PNM}}$	$\mathbf{W}_{\mathbf{D,D}}$
C_{FNM}: Non-market functions of olive growing	0	$\mathbf{W}_{\mathbf{FNM,D}}$

Table 2. (Cont.)

b) Supermatrix at element level

		C_{PNM}: Prioritization of non-market functions of olive growing	C_D: Demands of society on agriculture			
			D1	D2	…	D8
C_{PNM}: Prioritization of non-market functions of olive growing		1	0	0	…	0
C_D: Demands of society on agriculture	D1	$W_{D1,PNM}$	$W_{D1,D1}$	$W_{D1,D2}$	…	$W_{D1,Dp}$
	D2	$W_{D2, PNM}$	$W_{D2,D1}$	$W_{D2,D2}$	…	$W_{D2,Dp}$
	…	…	…	…	…	…
	D8	$W_{D8, PNM}$	$W_{D8,D1}$	$W_{D8,D2}$	…	$W_{D8,D8}$
C_{FNM}: Non-market functions of olive growing	FNM1	0	$W_{FNM1,D1}$	$W_{FNM1,D2}$	…	$W_{FNM1,Dd}$
	FNM2		$W_{FNM2,D1}$	$W_{FNM2,D2}$	…	$W_{FNM2,Dd}$
	…		…	…	…	…
	FNM8		$W_{FNM8,D1}$	$W_{FNM8,D2}$	…	$W_{FNM8,D8}$

Given the nullity of the market components, non-market net benefits associated with a change in farming practices from the modal farming pack to an alternative farming pack *A* are equivalent to the public net benefits for society:

$$\Delta U_{PU(A)} = \Delta U_{NM(A)} = \sum_{f=1}^{FNM} \omega_{FNMf} * \frac{(p_{FNMf(A)} - p_{FNMf(M)})}{p_{FNMf(M)}}$$

Estimating the social net benefits associated with a change in farming techniques entails integrating private net benefits for farmers with public net benefits. In order to enable comparisons among private and public indicators, we propose standardizing these net benefits in a similar way to (Qiu, 2005) and Parra-López et al. (2009):

$$\Delta U_{S(A)} = \Delta U'_{PR(A)} + \Delta U'_{PU(A)} = \frac{\Delta U_{PR(A)}}{\Delta U_{PRmax}} + \frac{\Delta U_{PU(A)}}{\Delta U_{PUmax}}$$

$$\Delta U_{S(A)} = \frac{\Delta GM_{(A)}}{\Delta U_{PRmax}} + \frac{\sum_{f=1}^{FNM} \omega_{FNMf} * \frac{p_{FNMf(A)} - p_{FNMf(M)}}{p_{FNMf(M)}}}{\Delta U_{PUmax}}$$

where $\Delta U_{S(A)}$ is the social net benefit associated with a change in farming practices from the modal farming pack to an alternative pack *(A);* $\Delta U'_{PR(A)}$ and $\Delta U'_{PU(A)}$ are the standardized private and public net benefits*;* ΔU_{PRmax} and ΔU_{PUmax} are the maximum possible improvements in private and public net benefits respectively, starting from the modal farming pack. They are mathematically defined as:

$$\Delta U_{PRmax} = max_{\forall \mathrm{O}}[\ \Delta GM_{(O)}]$$

$$\Delta U_{PUmax} = \ max_{\forall \mathrm{O}}\ [\Delta U_{PU(O)}] = max_{\forall \mathrm{O}}\ [\sum_{f=1}^{FNM} \omega_{FNMf} * \frac{p_{FNMf(O)} - p_{FNMf(M)}}{p_{FNMf(M)}}]$$

where *O* represents the optimal farming packs. These optimal packs are defined as the combinations of technical alternatives that maximize the performances achievable for every function, both market and non-market. 11 optimal farming packs were defined, one for each function (see section 2.2). The definition of $\Delta U_{S(A)}$ presupposes that improving the private performance of olive growing is just as important as improving its public performance. This is broadly consistent with social demand in Europe, given that 85% of people in the EU-25 think that, on key issues, political decision-makers should pay the same degree of attention to environmental concerns as to economic and social factors (EC, 2005).

The social net benefits can be standardized in a similar manner:

$$\Delta U'_{S(A)} = \frac{\Delta U_{S(A)}}{\Delta U_{Smax}}$$

where $\Delta U'_{S(A)}$ is the standardized social net benefit associated with a change in farming practices from the modal farming pack to an alternative pack *(A); and* ΔU_{Smax} is the maximum possible improvement in social net benefits starting from the modal farming pack. It is defined as:

$$\Delta U_{Smax} = \ max_{\forall \mathrm{O}}\ [\Delta U_{S(O)}]$$

2.3.2. Potential improvement in the sustainability of farming techniques

Farming practices with the highest potential to improve the sustainability of olive growing at farm-level are practices with the highest incidence on the social net benefits when changing the technical alternatives by which they are implemented, all other factors remaining equal and starting from the modal farming pack. To measure the degree of potential improvement, we propose an 'improvement of sustainability' index, $\mathrm{IS}_{(P)}$, for a given practice *P*, as follows:

$$\mathrm{IS}_{(\mathrm{P})} = max_{\forall \mathrm{A(P)}}[\ [\Delta U'_{S(A(P))}]] = \Delta U'_{S(Asost(P))}$$

where *A(P)* are the technical alternatives for practice P. The technical alternative for practice P that maximizes the standardized social net benefits is defined as the 'most sustainable technique' for this practice *($A_{sost(P)}$)*. The $IS_{(P)}$ index measures the potential increase of social benefits derived from a change of the modal technical alternative towards the most sustainable technique for a given practice.

2.3.3. Farming clusters according to private and public net benefits

A two-step cluster analysis (Bacher et al., 2004) was carried out to define homogeneous groups of farming packs, or farming clusters, according to their private and public net benefits ($\Delta U'_{PR(A)}$ and $\Delta U'_{PU(A)}$, respectively). Each farming pack is implemented by a surveyed olive grower. Therefore 400 farming packs were clustered. Subsequently, a bivariate statistical analysis of the farming practices implemented in the clusters was conducted. The aim was to identify those practices which were significantly different between clusters and which should be targeted by policies oriented to moving farmers towards the most sustainable clusters. Bivariate statistical correlations are based on: (1) Corrected Yates χ^2 for contingent tables when degrees of freedom (d.f.) = 1; (2) Pearson χ^2 for contingent tables when d.f. > 1; (3) χ^2 for bivariate logit when proof for contingent tables is not statistically reliable.

2.4. Policy design oriented to sustainability

In this methodological component, which corresponds to columns 3 and 4 of Figure 1, the aim is to define the most efficient policy mechanisms to implement if a given change of techniques is targeted from the modal situation. In particular, policies will be defined to promote change towards more sustainable farming techniques or packs. Some general criteria for determining whether there is a case for policy action are (1) whether it is technically possible to replace current modal farming techniques and, (2) whether this is economically efficient in the light of the costs and benefits involved (OECD, 2001; Parra-López et al., 2009). With regard to the first criterion, all analyzed techniques are technically feasible and may be changed in the short term, as previously stated. With regard to the second criterion, the framework used here for defining policy mechanisms is anchored within cost-effectiveness plane background (Campbell et al., 2007). The framework, named the Public/Private Benefits Framework (Pannell, 2008; Pannell et al., 2012), suggests a set of basic rules to define appropriate policy mechanisms to favour or avoid changes in farm practices as a function of their private and public net benefits (Table 3).

The framework recommends a mechanism based on extension (i.e. communication, education, etc.), positive incentives, negative incentives, technology development and no action. Potential incentive mechanisms consist of financial or regulatory instruments that may include polluter-pays mechanisms (e.g. command and control, pollution tax, offsets), beneficiary-pays mechanisms (e.g.

subsidies, conservation auctions and tenders), and market-based mechanisms (e.g. tradable pollution permits).

Table 3. Categories of policy mechanisms according to the Public/Private Benefits Framework

Category	Mathematical delimitation			Policy mechanism
	$\Delta U'_{PR(A)}$	$\Delta U'_{PU(A)}$	U'_S	
(A) Positive incentives	≤0	>0	>0	Financial or regulatory instruments to encourage change
(B) Extension	>0	≥0	>0	Technology transfer, education, communication, demonstrations, support for community network
(C) No action (or flexible negative incentives)	≥0	<0	≥0	Informed inaction
(D) Negative incentives	≥0	<0	<0	Financial or regulatory instruments to inhibit change
(E) No action (or extension or negative incentives)	<0	≤0	<0	Informed inaction
(F) Technology development (or no action)	≤0	>0	≤0	Development of improved land management options, such as through strategic R&D, participatory R&D with landholders, provision of infrastructure to support a new management option

$\Delta U'_{PR(A)}$, $\Delta U'_{PU}$, and $\Delta U'_S$ = standardised private, public and social net benefits (see section 2.3.1)

Source: Based on Pannell (2008) and Pannell et al. (2012)

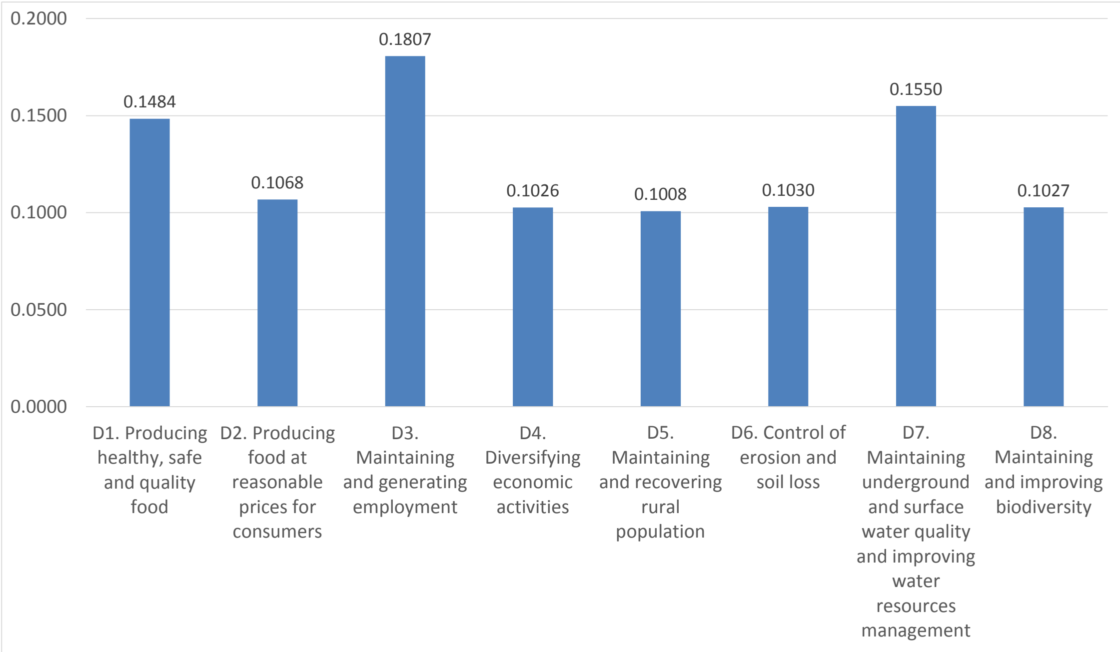
3. Results

3.1. Priorities of the non-market functions of olive growing for society

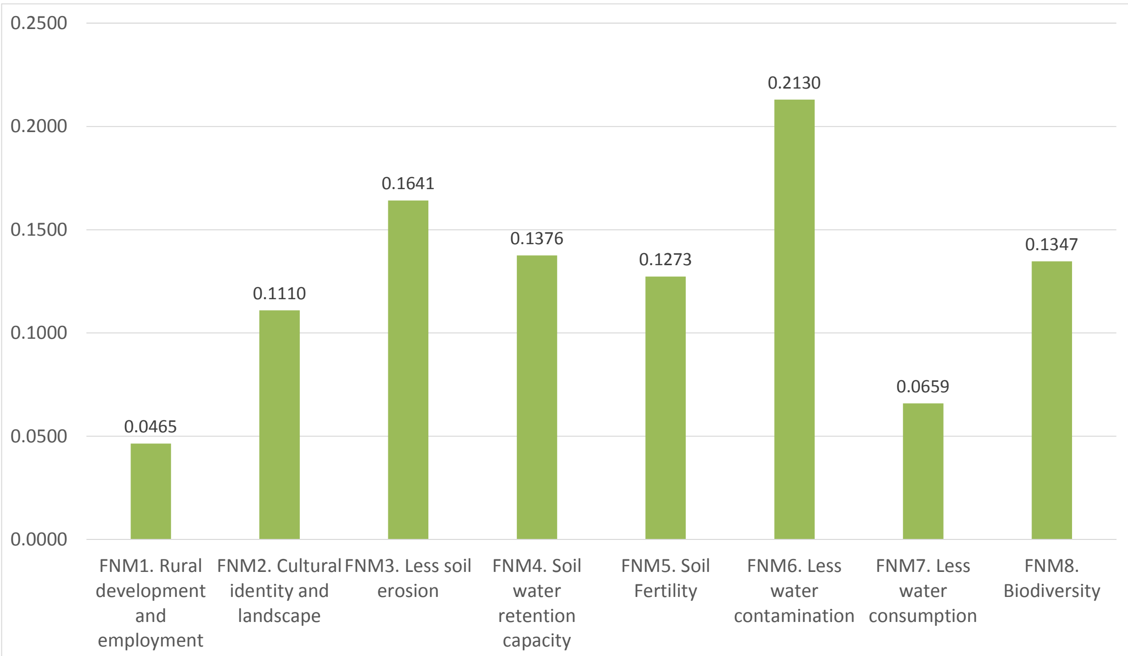
Three demands from Andalusian society on agriculture stand out (Figure 2.a): maintaining and generating employment -D3-, which is a social objective; maintaining underground and surface water quality and improving water resources management -D7-, which is an environmental target; and producing healthy, safe and quality food -D1-, which is mainly an economic target. According to all societal demands, and taking into account the inner relationships between them, the prime non-market functions of olive growing are of an environmental nature. In particular they are related to water (achieving low rates of water contamination, FNM6), soil (low erosion and good soil conditions, FNM3 and FNM4) and biodiversity (FNM8) (Figure 2.b).

Figure 2. Societal demands on agriculture and priorities of the non-market functions of olive growing

a) Demands of society on agriculture ($\mathbf{W_{D,PNM}}$)



b) Weights of the non-market functions of olive growing ($\boldsymbol{\omega_{FNM}}$) according to societal demands



3.2. Improvable farming practices and most sustainable techniques

Soil management –P2– is the individual farming practice with the highest potential by far to improve farm-level sustainability setting out from the modal situation ($IS_{(P2)}$=0.4902, Table 4). This means that by changing only its modal farming technique, bare soil, little tillage or shallow tillage, weed control with herbicides -A3(P2)-, to the most sustainable technique, soil cover of spontaneous or cultivated plants -A4(P2)-, *ceteris paribus*, social net benefits would increase the most ($\Delta U'_{S(Asost(P2))}$= $IS_{(P2)}$=0.4902, see section 2.3.2), due to the improvement of both private and public benefits.

The fertilizers used, if changed from inorganic to organic –A1(P9)-, and the implementation of analysis of soil or leaf before fertilization –A1(P10)-, also have a high impact on sustainability (Table 4). The best farming techniques for other highly improvable farming practices are: analysis of the quality of the irrigation water –A1(P6)-, applying fertilizers through the irrigation water (fertirrigation) –A2(P8)- instead of spraying the leaves, irrigating following expert advice –A2(P5)-, and low intensity pruning –A2(P22)- instead of traditional, severe pruning. In an intermediate position, some practices have a medium impact on sustainability. This is the case for the group of phytosanitation practices –GP5-, where no phytosanitation is the preferred technique, and for the irrigation system, where trickle irrigation is the best option. Finally, some farming practices have a low potential for improvement, mainly because the best farming techniques are already implemented. This is the case for olive variety -P1-, fertilization –P7-, and the group of harvesting practices –GP6-.

Table 4. Potential improvement of individual farming practices

			Modal farming techniques	Most sustainable farming techniques	Std. private net benefits [$\Delta U'_{PR(A)}$]	Std. public net benefits [$\Delta U'_{PU(A)}$]	Std. social net benefits [$\Delta U'_{S(A)}$]	Improvement of sustainability index [$IS_{(P)}$]
GP1.Planting	**P1. Olive variety**	A1(P1). Picual	•	•	0.0000	0.0000	0.0000	◆ 0.0000
		A2(P1). Hojiblanca			-0.0111	0.0001	-0.0059	
		A3(P1). Lechín de Sevilla			-0.0192	0.0013	-0.0096	
		A4(P1). Lechín de Granada			-0.0178	0.0013	-0.0088	
		A5(P1). Picudo			-0.0181	0.0004	-0.0095	
GP2. Soil management	**P2. Soil management**	A1(P2). Bare soil, conventional farming (constant tillage)			-0.2898	-0.1713	-0.2472	● 0.4902
		A2(P2). Bare soil, no tillage, weed control with herbicides			-0.1354	-0.1299	-0.1422	
		A3(P2). Bare soil, little tillage or shallow tillage, weed control with herbicides	•		0.0000	0.0000	0.0000	
		A4(P2). Soil covered by spontaneous or cultivated plants		•	0.4741	0.4404	0.4902	
GP3. Irrigation	**P3. Irrigation**	A1(P3). Irrigation		•	0.0833	0.0503	0.0716	▲ 0.0716
		A2(P3). No irrigation	•		0.0000	0.0000	0.0000	
	P4. Irrigation system	A1(P4). Trickle irrigation		•	0.0833	0.0503	0.0716	▲ 0.0716
		A2(P4). Sprinkler irrigation			0.0603	0.0444	0.0561	
		A3(P4). Flooding irrigation			0.0463	0.0365	0.0443	
		A4(P4). No irrigation	•		0.0000	0.0000	0.0000	
	P5. Timing of irrigation	A1(P5). On a fixed calendar basis (not depending on crop needs)			0.0833	0.0503	0.0716	● 0.0958
		A2(P5). Following expert advice (depending on crop needs)		•	0.1230	0.0558	0.0958	
		A3(P5). No irrigation	•		0.0000	0.0000	0.0000	
	P6. Analysis of the quality of the irrigation water	A1(P6). Analysis of water		•	0.1452	0.0970	0.1298	● 0.1298
		A2(P6). No analysis of water			0.0833	0.0503	0.0716	
		A3(P6). No irrigation	•		0.0000	0.0000	0.0000	
GP4. Fertilization	**P7. Fertilization**	A1(P7). Fertilization	•	•	0.0000	0.0000	0.0000	◆ 0.0000
		A2(P7). No fertilization			-0.1792	0.0292	-0.0804	
	P8. Method for the application of fertilizers	A1(P8). Direct application to the soil			0.0151	0.0046	0.0105	● 0.1015
		A2(P8). Fertilization through the irrigation water (fertirrigation)		•	0.1191	0.0703	0.1015	
		A3(P8). Spray application to the leaves	•		0.0000	0.0000	0.0000	
		A4(P8). No fertilization			-0.1792	0.0292	-0.0804	
	P9. Fertilizers used	A1(P9). Organic fertilizers (including pruning remains, compost, etc.)		•	0.2261	0.1778	0.2165	● 0.2165
		A2(P9). Inorganic fertilizers	•		0.0000	0.0000	0.0000	
		A3(P9). No fertilization			-0.1792	0.0292	-0.0804	
	P10. Analysis of soil or leaf before fertilization	A1(P10). Analysis of soil/leaf		•	0.2261	0.1778	0.2165	● 0.2165
		A2(P10). No analysis of soil/leaf	•		0.0000	0.0000	0.0000	
		A3(P10). No fertilization			-0.1792	0.0292	-0.0804	
GP5. Phytosanitation	**P11. Phytosanitation**	A1(P11). Phytosanitation	•		0.0000	0.0000	0.0000	▲ 0.0762
		A2(P11). No phytosanitation		•	-0.0491	0.1913	0.0762	
	P12. Treatment of olive fruit fly (Bractrocera oleae)	A1(P12). Mass trapping (one trap per tree=pheromones+glue+pyrethroids)			-0.0043	0.0065	0.0012	▲ 0.0762
		A2(P12). Biological control (Opius concolor)			-0.0037	0.0102	0.0035	
		A3(P12). Non-biological insecticide	•		0.0000	0.0000	0.0000	
		A4(P12). No phytosanitation		•	-0.0491	0.1913	0.0762	
	P13. Treatment of olive moth (Prays oleae)	A1(P13). Biological control (Bacillus thuringiensis)			-0.0049	0.0137	0.0047	▲ 0.0762
		A2(P13). Chemical treatments	•		0.0000	0.0000	0.0000	
		A3(P13). No phytosanitation		•	-0.0491	0.1913	0.0762	
	P14. Treatment of peacock spots (Spilocaea oleagina)	A1(P14). Pruning to clear			-0.0015	0.0106	0.0048	▲ 0.0762
		A2(P14). Copper fungicides	•		0.0000	0.0000	0.0000	
		A3(P14). Other chemical treatments			-0.0066	-0.0045	-0.0060	
		A4(P14). No phytosanitation		•	-0.0491	0.1913	0.0762	
	P15. Timing of phytosanitary treatments	A1(P15). On a fixed calendar basis or with the first symptoms of infestation/infection	•		0.0000	0.0000	0.0000	▲ 0.0762
		A2(P15). When the infestation/infection surpasses a threshold or following expert advice			0.0159	0.0156	0.0169	
		A3(P15). No phytosanitation		•	-0.0491	0.1913	0.0762	
	P16. Localization of phytosanitary treatments	A1(P16). The whole plantation	•		0.0000	0.0000	0.0000	▲ 0.0762
		A2(P16). Only the infestation/infection source			0.0076	0.0195	0.0145	
		A3(P16). No phytosanitation		•	-0.0491	0.1913	0.0762	
GP6. Harvesting	**P17. Timing of harvest**	A1(P17). According to a fruit ripeness index	•	•	0.0000	0.0000	0.0000	◆ 0.0000
		A2(P17). On a fixed calendar basis			-0.0139	-0.0014	-0.0082	
	P18. Method for collecting the fallen olives from the ground	A1(P18). By hand	•	•	0.0000	0.0000	0.0000	◆ 0.0000
		A2(P18). Mechanical means			0.0397	-0.0584	-0.0100	
		A3(P18). No picking			0.0136	-0.0688	-0.0296	
	P19. Method for picking the olives from the trees	A1(P19). Hand–pole beating			-0.0527	0.0318	-0.0112	◆ 0.0000
		A2(P19). Branch or trunk vibrators	•	•	0.0000	0.0000	0.0000	
		A3(P19). Handpicking			-0.0555	0.0280	-0.0147	
	P20. Separation of olives from ground/trees	A1(P20). Separation	•	•	0.0000	0.0000	0.0000	◆ 0.0000
		A2(P20). No separation			-0.0352	-0.0040	-0.0210	
	P21. Ways of carrying the olives from the olive grove to the olive mill	A1(P21). Sacks			-0.0083	-0.0004	-0.0047	◆ 0.0001
		A2(P21). Boxes		•	-0.0003	0.0005	0.0001	
		A3(P21). In the tractor or lorry trailer	•		0.0000	0.0000	0.0000	
GP7. Pruning	**P22. Pruning intensity**	A1(P22). Traditional, severe, every 1 or 2 years	•		0.0000	0.0000	0.0000	● 0.0831
		A2(P22). Low intensity pruning, every 2 or 3 years		•	0.1176	0.0375	0.0831	

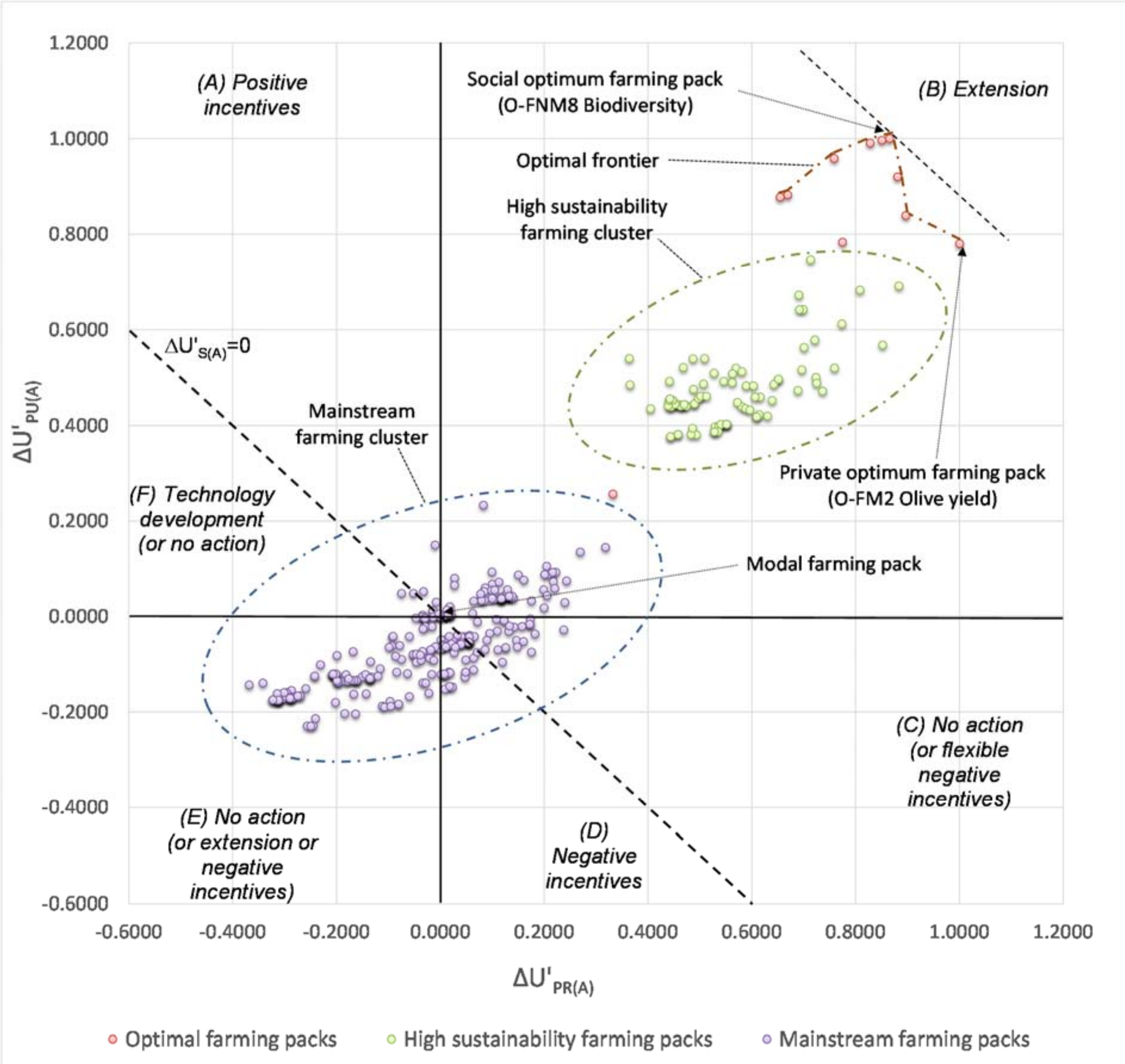
◆ ▲ ● *= Terciles for the $IS_{(P)}$ index: low, medium and high potential. See text for explanation of the index*

3.3. Mainstream, high sustainability and optimal farming packs

3.3.1. Mainstream vs. high sustainability farming clusters

The net benefits associated with the 400 farming packs corresponding to the surveyed farmers are represented in Figure 3. The policy mechanisms to promote or avoid the change of farming techniques from the modal to a given farming pack are shown as regions marked out by the X and Y axes and a dashed line for $\Delta U'_S=0$, ranging from (A) positive incentives to (F) technology development (or no action).

Figure 3. Net benefits for the mainstream, high sustainability and optimal farming techniques, and categories of policy mechanisms



Note: $\Delta U'_{PR(A)}$, $\Delta U'_{PU(A)}$, $\Delta U'_{S(A)}$ = standardized private, public and social net benefits (see section 2.3.1). The dashed line for $\Delta U_{S(A)}$=0 indicates null social net benefits from the modal farming pack. The parallel to this dashed line passing by the social optimum indicates the maximum social net benefits from the modal farming pack.

Two clusters of farming packs are clearly distinguishable: the ‘mainstream farming cluster’ and the ‘high sustainability farming cluster’. The high sustainability cluster performs significantly better from both the private (change in $\Delta U'_{PR(A)}$ = 0.5837, Table 5.a) and the public (change in $\Delta U'_{PU(A)}$ = 0.5224) perspective, therefore proving to be more globally sustainable (change in $\Delta U'_{S(A)}$ = 0.5930). A change from the modal farming pack towards any farming pack of the high sustainability cluster may be promoted through ‘extension’, making olive growers aware of the private benefits they can gain from this change (1312.63 € ha^{-1}, on average, Table 5.a). Furthermore, they may become increasingly aware of the public benefits associated with this change.

Table 5. Mainstream and high sustainability farming clusters

a) Gross margin and net benefits

		Mainstream farming cluster	High sustainability farming cluster	Change	ANOVA (Sign.)
Gross margin [GM] (€ ha^{-1})	Mean	924.80	2237.43	1312.63	.000(**)
	Standard Error of Mean	18.68	24.04	5.37	
	Maximum	1714.34	2985.14	1270.80	
	Minimum	171.25	1817.23	1645.97	
Std. private net benefits [$\Delta U'_{PR(A)}$] ()	Mean	-.0331	.5506	.5837	.000(**)
	Standard Error of Mean	.0083	.0107	.0024	
	Maximum	.3179	.8831	.5652	
	Minimum	-.3682	.3637	.7319	
Std. public net benefits [$\Delta U'_{PU(A)}$] ()	Mean	-.0615	.4609	.5224	.000(**)
	Standard Error of Mean	.0047	.0071	.0023	
	Maximum	.2333	.7467	.5134	
	Minimum	-.2298	.3766	.6064	
Std. social net benefits [$\Delta U_{S(A)}$] ()	Mean	-.0508	.5422	.5930	.000(**)
	Standard Error of Mean	.0066	.0087	.0021	
	Maximum	.2479	.8441	.5962	
	Minimum	-.2744	.4396	.7140	

*Significance (sign.): ** p ≤ 0.01; * 0.01< p ≤ 0.05; n.s. = not significant; () = Dimensionless*

b) Significant differences in farming techniques for the most improvable practices

	Absolute frequencies and percentages		Correlation statistics[(+)]	
	Mainstream farming cluster	High sustainability farming cluster	χ^2(d.f.)	p(sign.)
SOIL MANAGEMENT				
P2. Main soil management technique [(H)]			400.000(3)	0.000(**)
– A1(P2). Bare soil, conventional farming (constant tillage)	66(22.1)^a	0(0.0)^b		
– A2(P2). Bare soil, no tillage, weed control with herbicides	85(28.4)^a	0(0.0)^b		
– A3(P2). Bare soil, little tillage or shallow tillage, weed control with herbicides	148(49.5)^a	0(0.0)^b		
– A4(P2). Soil covered by spontaneous or cultivate plants	0(0.0)^a	101(100.0)^b		
FERTILIZATION				
P8. Method for the application of fertilizers [(H)]			15.717(2)	0.000(**)
– A1(P8). Direct application to the soil	136(45.6)^a	42(41.6)^a		
– A2(P8). Fertilization through the irrigation water (fertirrigation)	8(2.7)^a	13(12.9)^b		
– A3(P8). Spray application to the leaves	154(51.7)^a	46(45.5)^a		
P9. Fertilizers used [(H)]			14.186(1)	0.000(**)
– A1(P9). Organic fertilizers (including pruning remains, compost, etc.)	0(0.0)^a	6(5.9)^b		
– A2(P9). Inorganic fertilizers	298(100.0)^a	95(94.1)^b		
PHYTOSANITARY TREATMENTS				
P12. Treatment of olive fruit fly (*Bractrocera oleae*) [(M)]			11.496(2)	0.003(**)
– A1(P12). Mass trapping (one trap per tree = pheromones + glue + pyrethroids)	1(0.3)^a	2(2.0)^a		
– A2(P12). Biological control (*Opius concolor*)	2(0.7)^a	7(6.9)^b		
– A3(P12). Non-biological insecticide	292(99.0)^a	93(91.2)^b		
P13. Treatment of olive moth (*Prays oleae*) [(M)]			14.036(1)	0.000(**)
– A1(P13). Biological control (*Bacillus thuringiensis*)	0(0.0)^a	6(5.9)^b		
– A2(P13). Chemical treatments	295(100.0)^a	95(94.1)^b		
P15. Timing of phytosanitary treatments [(M)]			16.342(1)	0.000(**)
– A1(P15). On a fixed calendar basis or with the first symptoms of infestation/infection	233(79.0)^a	59(57.8)^b		
– A2(P15). When the infestation/infection surpasses a threshold or following expert advise	62(21.0)^a	43(42.2)^b		

*[(+)]Corrected Yates χ^2 for contingent tables when degrees of freedom (d.f.) = 1; (2) Pearson χ^2 for contingent tables when d.f.> 1; (3) χ^2 for bivariate logit when proof for contingent tables is not statistically reliable. Significance (sign.): ** p ≤ 0.01; * 0.01< p ≤ 0.05; n.s. = not significant. y/n = yes/no; a,b: Subscript letters denotes for a given technical alternative at .95 confidence level that proportions do (if a,b) or do not significantly differ (if a,a) between clusters; (H)/(M): Farming practices with a high/medium potential of improvement (see Table 4)*

The farming practices which are implemented differently in the two clusters are shown in Table 5.b. In the high sustainability cluster the following techniques are more frequent than in the low sustainability cluster: soil cover -A4(P2)-, fertirrigation -A2(P8)-, organic fertilizers -A1(P9)-, biological control of olive fruit fly -A2(P12)- and olive moth –A1(P13)-, and treating when the infestation/infection surpasses a threshold or following expert advice -A2(P15). These techniques should be targeted as a whole by those policies oriented to moving farmers towards the most sustainable cluster.

3.3.2. Optimal farming packs

Eleven optimal farming packs were defined (see section 2.2) which are indicated in Figure 3. They are the farming packs that maximize each of the analyzed functions of olive growing. They represent a frontier of the private and public benefits' joint production function. Gross margin and its components, the performance in each function and the net benefits associated with each optimal farming pack are shown in Table 6.a. Two optimal and, to some extent, opposing packs stand out: the optimum for olive yield –O-FM2–, which maximizes the private net benefits of farmers and will be referred to as the private optimum farming pack; and the optimum for biodiversity –O-FNM8–, which maximizes the public ($\Delta U'_{PU(A)} = 1$) and also the social net benefits ($\Delta U'_{S(A)} = 1$) and will be referred to as the public optimum farming pack (Figure 3 and Table 6.a).

The private optimum farming pack entails maximizing olive yield –O-FM2– which is a plausible strategy for more professional farmers with a clear market orientation. Private benefits are maximized despite a small reduction in olive quality. Public benefits are also high ($\Delta U'_{PU(A)} = 0.7803$, Table 6.a) since its performance in social and environmental functions is over 0.6000 in all cases (e.g. its performance in function FNM4 'soil water retention capacity', $pFNM4_{(O\text{-}FM2)} = 0.9009$; Table 6.a). The changes needed in the most improvable farming practices to implement this pack, setting out from the modal farming pack, are as follows (Table 6.b): use of soil cover instead of bare soil and little or shallow tillage, application of fertilizers through irrigation water instead of spraying the leaves, use of organic fertilizers instead of inorganic ones, trickle irrigating following expert advice and analyzing water instead of not irrigating, phytosanitation according to a threshold or following expert advice instead of on a fixed calendar basis and only at the infestation/infection source, not on the whole plantation, and low intensity pruning, every 2 or 3 years, instead of a traditional pruning, every 1 or 2 years.

Table 6. Optimal farming packs

a) Gross margin and its components, multifunctional performance and net benefits

	Modal farming pack	O-FM1. Lower production costs	O-FM2. Olive yield	O-FM3. Product quality	O-FNM1. Rural dev. & employment	O-FNM2. Cultural identity and landscape	O-FNM3. Less soil erosion	O-FNM4. Soil water retention capacity	O-FNM5. Soil fertility	O-FNM6. Less water contamination	O-FNM7. Less water consumption	O-FNM8. Biodiversity
Y (olive yield) (kg olives ha^{-1})	4870	7402	10000	6908	9518	8736	9101	8989	9192	7502	7563	9231
P (price) (€ kg $olives^{-1}$)	0.41	0.40	0.40	0.42	0.41	0.40	0.39	0.41	0.39	0.39	0.39	0.39
VC (variable costs) (€ ha^{-1})	1807.00	1076.20	1555.50	1956.80	1745.00	1625.90	1538.90	1491.10	1523.90	1288.90	1280.20	1507.10
S (subsidies) (€ ha^{-1})	826.44	826.44	826.44	826.44	826.44	826.44	826.44	826.44	826.44	826.44	826.44	826.44
GM (gross margin) [Y*P-VC+S] (€ ha^{-1})	999.35	2741.05	3248.13	1746.63	3015.43	2704.60	2860.67	2979.50	2911.14	2471.13	2504.04	2945.57
FM1. Lower production costs ()	0.4752	1.0000	0.6558	0.3677	0.5198	0.6053	0.6678	0.7021	0.6785	0.8472	0.8535	0.6906
FM2. Olive yield ()	0.3782	0.6851	1.0000	0.6252	0.9416	0.8468	0.8911	0.8774	0.9020	0.6972	0.7047	0.9068
FM3. Product quality ()	0.7665	0.7073	0.5585	1.0000	0.9256	0.6380	0.4378	0.7395	0.4378	0.4020	0.4020	0.4434
FNM1. Rural dev. & employment ()	0.4636	0.5008	0.7813	0.5732	1.0000	0.8640	0.7901	0.6835	0.8008	0.6728	0.6734	0.8135
FNM2. Cultural identity and landscape ()	0.5454	0.3250	0.6995	0.4437	0.9692	1.0000	0.9572	0.5591	0.9524	0.8408	0.8452	0.9578
FNM3. Less soil erosion ()	0.2520	0.8030	0.8800	0.4690	0.8999	0.9590	1.0000	0.9432	0.9994	0.8700	0.8794	0.9994
FNM4. Soil water retention capacity ()	0.2131	0.8845	0.9009	0.4937	0.8919	0.9397	0.9728	1.0000	0.9726	0.8482	0.8582	0.9726
FNM5. Soil Fertility ()	0.1741	0.8110	0.8408	0.4340	0.8673	0.9647	0.9963	0.9617	1.0000	0.8542	0.8594	1.0000
FNM6. Less water contamination ()	0.2462	0.9334	0.7698	0.3665	0.8155	0.9560	0.9760	0.9309	0.9883	1.0000	0.9951	0.9950
FNM7. Less water consumption ()	0.5280	0.9956	0.7378	0.3496	0.7327	0.7222	0.7122	0.7086	0.7353	0.9924	1.0000	0.7544
FNM8. Biodiversity ()	0.1554	0.8082	0.7811	0.4009	0.8281	0.9642	0.9970	0.9467	0.9999	0.8782	0.8784	1.0000
$\Delta U_{PR(A)} = \Delta GM_{(A)}$ (€ ha^{-1})	0.00	1741.69	2248.78	747.27	2016.08	1705.24	1861.32	1980.14	1911.79	1471.78	1504.68	1946.22
$\Delta U'_{PR(A)}$ ()	0.0000	0.7745	1.0000	0.3323	0.8965	0.7583	0.8277	0.8805	0.8501	0.6545	0.6691	0.8655
$\Delta U'_{PU(A)}$ ()	0.0000	0.7836	0.7803	0.2566	0.8391	0.9586	0.9907	0.9201	0.9966	0.8775	0.8821	1.0000
$\Delta U'_{S(A)}$ ()	0.0000	0.8352	0.9543	0.3157	0.9304	0.9204	0.9748	0.9652	0.9900	0.8212	0.8315	1.0000

() = Dimensionless

Table 6. (Cont.)

b) Comparison of farming techniques for the most improvable practices with some selected optimal farming packs

		Modal farming pack	Private optimum farming pack (O-FM2. Olive yield)	Public optimum farming pack (O-FNM8. Biodiversity)
GP2. Soil management	P2. Soil management (H)	A3(P2). Bare soil, little tillage or shallow tillage, weed control with herbicides	A4(P2). Soil covered by spontaneous or cultivated plants	A4(P2). Soil covered by spontaneous or cultivated plants
GP3. Irrigation	P3. Irrigation (M)	A2(P3). No irrigation	A1(P3). Irrigation	A1(P3). Irrigation
	P4. Irrigation system (M)	A4(P4). No irrigation	A1(P4). Trickle irrigation	A1(P4). Trickle irrigation
	P5. Timing of irrigation (H)	A3(P5). No irrigation	A2(P5). Following expert advice (depending on crop needs)	A2(P5). Following expert advice (depending on crop needs)
	P6. Analysis of the quality of the irrigation water (H)	A3(P6). No irrigation	A1(P6). Analysis of water	A1(P6). Analysis of water
GP4. Fertilization	P8. Method for the application of fertilizers (H)	A3(P8). Spray application to the leaves	A2(P8). Fertilization through the irrigation water (fertirrigation)	A2(P8). Fertilization through the irrigation water (fertirrigation)
	P9. Fertilizers used (H)	A2(P9). Inorganic fertilizers	A1(P9). Organic fertilizers (including pruning remains, compost, etc.)	A1(P9). Organic fertilizers (including pruning remains, compost, etc.)
	P10. Analysis of soil or leaf before fertilization (H)	A2(P10). No analysis of soil/leaf	A2(P10). No analysis of soil/leaf	A2(P10). No analysis of soil/leaf
GP5. Phytosanitation	P11. Phytosanitation (M)	A1(P11). Phytosanitation	A1(P11). Phytosanitation	A2(P11). No phytosanitation
	P12. Treatment of olive fruit fly (Bractrocera oleae) (M)	A3(P12). Non-biological insecticide	A3(P12). Non-biological insecticide	A4(P12). No phytosanitation
	P13. Treatment of olive moth (Prays oleae) (M)	A2(P13). Chemical treatments	A2(P13). Chemical treatments	A3(P13). No phytosanitation
	P14. Treatment of peacock spots (Spilocaea oleagina) (M)	A2(P14). Copper fungicides	A2(P14). Copper fungicides	A4(P14). No phytosanitation
	P15. Timing of phytosanitary treatments (M)	A1(P15). On a fixed calendar basis or with the first symptoms of infestation/infection	A2(P15). When the infestation/infection surpasses a threshold or following expert advice	A3(P15). No phytosanitation
	P16. Localization of phytosanitary treatments (M)	A1(P16). The whole plantation	A2(P16). Only the infestation/infection source	A3(P16). No phytosanitation
GP7. Pruning	P22. Pruning intensity (H)	A1(P22). Traditional, severe, every 1 or 2 years	A2(P22). Low intensity pruning, every 2 or 3 years	A2(P22). Low intensity pruning, every 2 or 3 years

(H)/(M): Farming practices with a high/medium potential of improvement (see Table 4)

The public optimum farming pack, however, entails maximizing biodiversity –O-FNM8– and may be a more valid option for part-time olive growers. It may be more attractive for growers if CAP agri-environmental subsidies are eventually targeted at these kinds of environmentally friendly techniques. This farming pack also maximizes the social net benefits and thus is the most socially desirable. In effect, the private net benefits of the pack are also very high (ΔGM = 1946.22 € ha^{-1}; Table 6.a), because of a significant increase in olive yield and decrease in production costs, and despite a reduction in product quality. The performances in social –FNM1 and FNM2- and environmental –FNM3 to FNM8- functions are very much increased in comparison with the modal pack (Table 6.a). This optimal farming pack would require the same changes in the most improvable practices as for the optimum for olive yield (Table 6.b), with the exception of phytosanitation where non-treatment is mandatory. No phytosanitation, which is proposed by some types of organic farming, will maximize biodiversity, which has a positive impact on the environmental conditions of olive groves, although this slightly reduces product quality with respect to the modal pack (Table 6.a).

4. Discussion

Evaluating and improving the sustainability of agriculture poses problems of high complexity, uncertainty and risk. It entails the joint consideration of economic, environmental and social functions of agriculture and taking into account private and public benefits and costs for the productive sector, consumers, public administration and society in general. The 'public goods' character of many non-market functions of agriculture frequently makes public intervention necessary to fulfil societal interests (Zander et al., 2008). The relevant scientific literature mainly focuses on the analysis of the supply of multiple functions of agriculture. However, information is scarce in the public debate on what society really demands, particularly with regard to the social goals of multifunctionality (Rossing et al., 2007) and, by extension, the optimal supply of public goods by agriculture (Hall et al., 2004). The satisfaction of societal demand for non-commodities and the level of sustainability determines how far a certain type of agricultural production activity should be fostered by society (Zander et al., 2008). Societal demands are usually evaluated using stated-preference techniques for monetary valuation such as Contingent Valuation, Travel Costs and Contingent Ranking (Lima e Santos, 2001), and more recently Choice Experiments and related techniques derived from Conjoint Analysis (Zander et al., 2008). These methodologies are in general based on the simulation of a market through a questionnaire, recording individuals' willingness to pay for a given change to occur or not. Stoorvogel et al. (2004) argue that with a low public acceptance of monetary valuations, the analysis of the trade-offs between market and non-market production (economic versus ecological and social performance) can be useful for public policy decision-making. Alternative and innovative methodological mixes are needed (Zander et al., 2008).

The integrated methodological framework developed and applied in this research attempts to contribute to theory and practice in this sense by combining economic valuation, integrated modelling, stakeholder analysis, and multi-criteria evaluation. MCDA, through ANP, was combined with a classic economic analysis and a public/private benefits framework for cost-effective policy design. All relevant stakeholders were considered. MCDA has a weaker theoretical basis that monetary methods but offers greater flexibility on not being circumscribed by the strict utility-based theoretical design requirements (Hall et al., 2004). Hence traditional areas of Decision Theory criticise certain axioms and principles of ANP (Parra-López et al., 2008a). In terms of strengths, ANP allows the incorporation of qualitative, subjective and intangible information. ANP is a process for decision making in which learning, improvement of the decision-making process, negotiation and consensus, in accordance with Procedural Rationality, is more important than the search for an optimal solution, which is the main aim of classical Substantive Rationality (Moreno Jiménez, 1997; Oconnor et al., 1996). This is in agreement with the new bottom-up, integrated trend in landscape policy, involving the participation of local stakeholders and a transdisciplinary approach to integrate academic researchers with non-academic partners, such as managers, administrators, and the local public (Sevenant and Antrop, 2010). ANP allows an evaluation of the sustainability of agriculture which is more in accordance with the rationale of Post-Normal Science and Ecological Economics (Funtowicz and Ravetz, 1991).

From a policy design perspective, if the EU wishes to uphold the principle of 'public money for public goods' and to see a real greening of agriculture, the Common Agricultural Policy (CAP) should move money away from untargeted direct payments and towards targeted payments and support for farming techniques which demonstrate a high potential to deliver environmental and climatic benefits. Proposals in relation to good farming practices should distinguish between conditions that should be obligatory (cross-compliance) and those that should be paid for (Gómez et al., 2004). In general, the results demonstrate that techniques such as soil cover, organic fertilization, analysis of soil or leaf before fertilization, analysis of the quality of the irrigation water, fertirrigation, irrigating following expert advice and low intensity pruning should be promoted. Moreover, these techniques should be targeted as a whole by policies, due to the synergies between farming techniques. Access to water may be the most limiting aspect in achieving this.

Public policies must remove the short-term financial, technical and informational barriers that deter growers from adopting more sustainable farming techniques. As suggested by the Public/Private Benefits Framework (Pannell, 2008; Pannell et al., 2012), policies must not be restricted to financial measures directed at farmers, such as green payments and agri-environment schemes (AES). In fact, our results reveal that the most cost-effective policy mechanism to achieve sustainability is extension, i.e. technology transfer, education, communication, demonstrations, support for community networks. This highlights the importance of reinforcing the support (without necessarily offering additional monetary resources) and relevance of certain R&D agents such as Public Research Centres and Training Agencies. Moreover, this suggests the significant effects that some Rural Development measures of the new CAP should have (EC, 2013), related to 1) innovation, by promoting greater cooperation between agriculture and research in order to accelerate technological transfer to farmers; 2) knowledge, by empowering the role of Farm Advisory Services; and 3) cooperation, by promoting pilot projects and joint contracts between farmers or groups of farmers and public administrations for the supply of environmental services, such as the territorial contracts. AES can also be used to channel public support for sustainability. In fact, the most sustainable farming techniques identified are essentially in keeping with those proposed by Integrated Production, regulated in Andalusia by the Order of 15 April 2008 (BOJA num.83). These are techniques for the care of soil, water and biodiversity, issues highly demanded by society as our results show, with a very relevant direct effect on the environmental performance and an indirect effect on the economic and social performance of olive growing. Infrastructure policies promoting irrigation should also be targeted, which is in agreement with other studies (Villanueva et al., 2014).

The results are in agreement with the recognised dual productive/multifunctional nature of olive production in Andalusia and CAP support for agriculture (Gallardo et al., 2003). Hence social benefits can be maximized through two very different strategies: 1) by maximizing the private benefits of farmers, which is a sound target for growers oriented to productivity and efficiency under the 1st Pillar of the CAP; and 2) by maximizing public benefits, which is a better strategy for growers oriented to the environmental concerns and rural development of the 2nd Pillar. However, this contradiction is only apparent because both optimums achieve very high sustainability indexes. This demonstrates that maximizing social benefits is not contradictory with improving the private net benefits of farmers. In any case, it is important to qualify these results since they were obtained for the average agro-climatic, environmental and socio-institutional conditions of olive cultivation in Andalusia. However, olive growing in the region is very diverse in structural, social and environmental terms. The results may change in other conditions and need to be further investigated in order to tailor policy design.

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Artículo 3.

Integrating public demands into model-based design for multifunctional agriculture: An application to intensive Dutch dairy landscapes

[Integración de las demandas públicas en el diseño basado en modelos para una agricultura multifuncional: Una aplicación a la ganadería intensiva neerlandesa a nivel de paisaje]

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Abstract

The contribution of agriculture to the welfare of society is determined by its economic, social and environmental performance. Although theoretical discussions can be found in the literature, few reports exist that integrate the social demand for multifunctional agriculture in the evaluation of the sustainability and the global welfare of society. This paper presents a methodology that combines economic valuation, integrated modelling, stakeholder analysis, and multi-criteria evaluation. It consists of three steps to determine: (1) social demands for multifunctional agriculture; (2) feasible technical alternatives available from the supply part of the market; (3) the net utility of alternatives for society measured as the change in social net benefit, i.e. the sum of changes compared to the current situation expressed in utility of market and non-market net benefits. Market net benefits are represented by their monetary value. Quality Function Deployment combined with Analytic Network Process (QFD/ANP) were used to estimate the non-market net benefits. The methodology is applied to the case study of a dairy-farming based agricultural landscape in the Northern Friesian Woodlands, The Netherlands. Social net benefit depended on land use, i.e. pasture management regimes on each of the agricultural fields and on presence or absence of hedgerows around the fields. Changes in market net utility were expressed in terms of changes for farmers, consumers and government. Changes in non-market net utility were expressed in terms of changes in landscape quality, nature value and environmental health for Dutch society as a whole, as estimated from European public surveys (Eurobarometer). The complete solution space defined by the market and non-market net benefits of landscapes with alternative patterns of land use was estimated to offer insight in the trade-off between market and non-market performance and enable selection of 'icon' landscapes to target or avoid. Improvement of the current landscape towards the social optimum would involve changes in pasture management resulting in higher gross margin for farmers, slightly relaxing current environmental restrictions, which could be reached at lower levels of subsidies in agri-environmental programs. In addition to such overall optimum the results demonstrate the trade-off between market and non-market benefits and the characteristics of current, utopian and dystopian landscapes. The approach provides an alternative to current economic valuation methods which focus on assessment of economic value as an input to analysis. Here, economic value emerges as the trade-off between market and non-market functions which is an output of the analysis.

Key words: public preferences, sustainable agriculture, multifunctionality, landscape, environmental cooperatives, social net benefit.

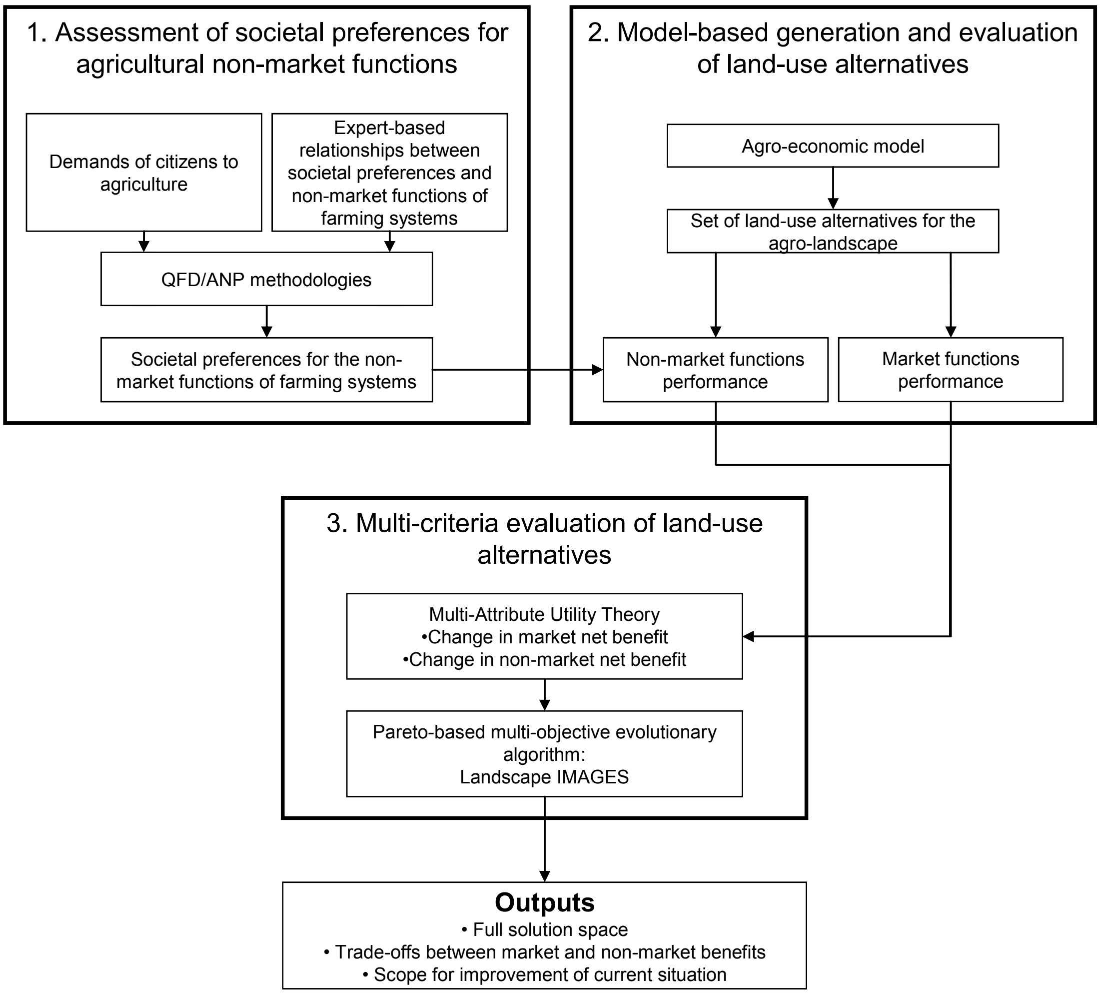
1. Introduction

The concept of multifunctionality has generated ample debate in political and academic spheres and different interpretations can be found. However, there is no established terminology to describe its key elements (OECD, 2001b). Multifunctionality refers to the fact that an economic activity (usually agriculture is referred to) may have multiple outputs and, by virtue of this, may contribute to several social objectives at once. Multifunctionality can be seen either as a characteristic of an activity without a necessarily intrinsic value (positive view) or as a desirable objective of the activity (normative view). In this study we adopt the second perspective since we consider multifunctional agriculture potentially socially valuable and therefore a goal for agricultural activities is to try and satisfy social demand. From the 1980s onwards new demands of society to agriculture increased, related to concepts such as sustainable agriculture, environmentally friendly agricultural practices and responsible management of natural resources. These ideas refer to the ecological, technological and socioeconomic dimensions of the broader concept of sustainable development (Harwood, 1990), and implicitly allude to the multifunctional nature of agriculture.

At present, awareness among rural and urban citizens of the positive and negative effects of agriculture beyond commodity production is growing and governments are increasingly looking for ways to ensure that the non-commodity outputs of agriculture correspond in quantity, composition and quality to those demanded by society (OECD, 2003). Delivering to growing public demands raises two main questions for farmers and policy makers: (1) what might the public actually want (Hall et al., 2004); (2) how to integrate preferences of citizens in the evaluation of the multifunctional performance and the sustainability of alternative land use options. An increasing number of studies address integrated and holistic evaluation of the economic, environmental and social impacts of human activities, in general, and of land use and agricultural production in particular (e.g. Parker et al., 2002; Osinski et al., 2003; Van Calker et al., 2006 and 2007; Rossing et al., 2007; Van Keulen, 2007; Van Ittersum et al., 2008). Economic studies can be divided into those that focus on economic valuation of landscapes and their elements, and those that integrate economic aspects within land-use modelling (Osinski et al., 2003), roughly corresponding to the distinct and sometimes conflicting approaches of Environmental Economics and Ecological Economics, respectively (Parra-López et al., 2004). Turner et al. (2000) suggested that integrating key elements in an approach that combines economic valuation, integrated modelling, stakeholder analysis, and multi-criteria evaluation can provide complementary insights into sustainable and welfare-optimizing management and policy. In this paper we investigate these suggestions.

The main objective of this paper is to propose and apply a methodological framework to integrate the social demand for multifunctionality of agriculture in the evaluation and design of more sustainable agro-landscapes composed of dairy farming systems. The methodology will be illustrated in a case study of an intensively managed, ecologically and historically valuable agricultural landscape in the Northern Friesian Woodlands (The Netherlands). The description of the case study is provided in section 2. The methodological framework (Figure 1) consists of three interconnected components which are introduced in sections 3 to 5. In section 3 social preferences for agricultural non-market functions are prioritized using a novel application of the multi-criteria decision analysis techniques of Quality Function Deployment and Analytic Network Process (QFD/ANP). In section 4 the social preferences for non-market functions are combined with benefits from market functions to arrive at social net benefit based on the neoclassical concept of utility. Finally in section 5, the Landscape IMAGES model is used to generate and evaluate alternative landscapes and to reveal trade-offs between market and non-market functions. The results (section 6) demonstrate the alternative development options for the case study landscape and highlight opportunities and pitfalls for further improvement of social net benefit.

Figure 1. Methodological scheme of the research



2. The case study: Northern Friesian Woodlands, The Netherlands

The case study focuses on an intensively managed agricultural landscape in the Northern Friesian Woodlands (The Netherlands). This region is characterized by a small scale landscape on predominantly sandy soils with dairy farming as the prevailing land-use activity. On some farms a limited proportion of up to 5% of the area is used for forage maize production, while the rest of the area is occupied by permanent grassland, rotationally grazed and mown. The fields with an average size of 2 ha are often surrounded by hedgerows and frequently border on ponds. The average grazing season lasts 6 months from May to October. Grazing systems range from day and night grazing to restricted and zero grazing. The bio-physical farm and field characteristics and the social demands as articulated in regulations to maintain landscape and land-use have limited the possibilities to convert to large scale agriculture in the past. On the other hand, the region offers ample opportunities to provide non-productive amenities, the remuneration of which has recently been argued to sustain farming in the area (Berentsen et al., 2007).

In the 1990s, the farmers were confronted with strict regulations to reduce emissions of ammonia and nitrate to the environment. Environmental cooperatives VEL (Vereniging Eastermar's Lânsdouwe) and VANLA (Vereniging Agrarisch beheer Natuur en Landschap in Achtkarspelen) emerged in the Northern Friesian Woodlands as a response to predominantly generic and means-oriented policy interventions. The cooperatives developed activities to reach the aims of the proposed policies with context-specific measures that were acceptable for farmers. In addition the farmers committed themselves to maintaining the historical landscape which is the basis for a strong local identity of its inhabitants and the cooperatives organized activities related to nature and landscape management by farmers (Renting and Van der Ploeg, 2001; Wiskerke et al., 2003; Anonymous, 2005).

Here we focus on three key non-market functions that are supported by the activities of the environmental cooperatives:

F1. *Landscape quality (LQ)*: This function refers to variation in number of plant species in pasture and to irregularity in the hedgerow pattern, referred to as half-openness of the landscape, and thus pertains to the spatial scales of field and landscape.

F2. *Nature value (NV)*: This function refers to high species diversity in the grass swards and hedgerows (number of species per ha). This function is relevant at the field scale.

F3. *Environmental health (EH)*: Low nitrogen loss from agriculture, here also interpreted at the field scale.

In this paper we will explore opportunities to satisfy both the non-market and the market functions by adapting agricultural land use and land management in an area of 232 ha, comprising three farms. As indicator of the market function we use landscape gross margin (GM), which is defined as the total revenues minus all variable costs, at the landscape scale. The impact of land use and land management is expressed in variable costs and will become apparent in changes in gross margin rather than total economic results, which also include fixed costs (Ondersteijn et al., 2003). Although we distinguish farms to evaluate technical constraints related to ratio between grazed and mown herbage and the maximum allowed fertilizer application rates, we focus on landscape gross margin rather than the farm gross margin for evaluation of on market function to avoid excess detail in disaggregating individual farm gross margin. This aspect is however required for policy design at farm level which will be covered in subsequent research of the present authors.

3. Prioritizing agricultural non-market functions based on social preferences

The market function of agriculture is assumed to be valued in the market, which reflects preferences and demands of consumers in a monetary value. In contrast, non-market functions are not valued in a market and therefore lack a monetary value, but could affect the welfare of society. In such case preferences of all citizens may be used as a proxy to reflect potential demand. In this section, two methodologies (QFD and ANP) will be combined to estimate social preferences for non-market functions of agro-landscapes.

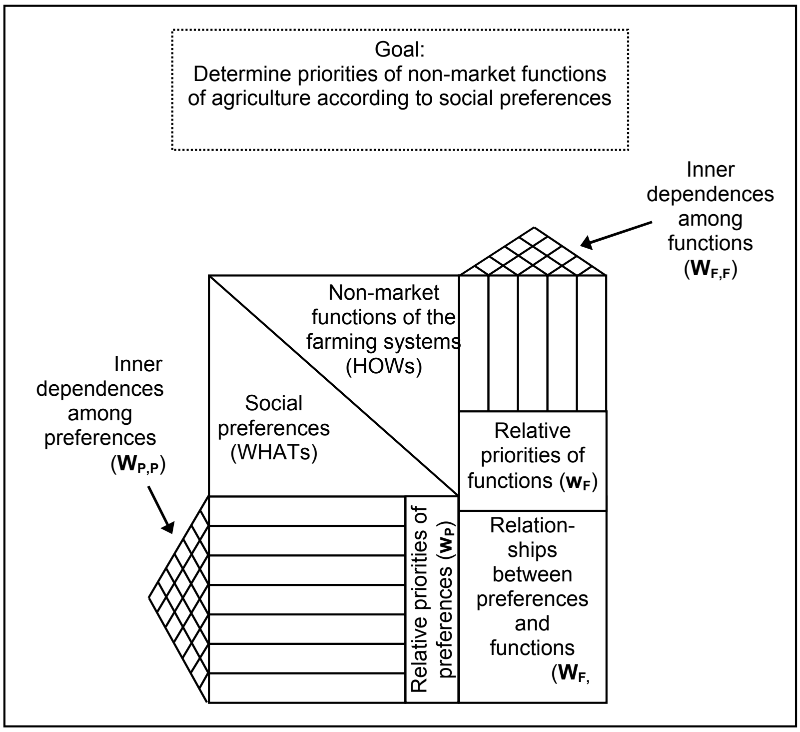
3.1. The QFD/ANP methodologies

Quality Function Deployment (QFD) is an analytical tool first conceptualized in Japan in the late 1960s (Akao, 1997) within psychology and marketing, with the aim of allowing firms to incorporate the preferences of consumers in the design stage of the product planning. Following the seminal paper by Kogure and Akao (1983) QFD spread to multiple applications especially in the USA. For an extensive literature review of general applications of QFD, see Chan and Wu (2002), and for specific agri-food case studies see Benner et al. (2003). Despite the broad application of QFD, its implementation in public planning of agriculture is missing from the literature.

QFD proposes a core scheme for strategic planning (e.g., Bergquist and Abeysekera, 1996; Govers, 1996), which can be represented by a decisional structure named the “House of quality” (HoQ) (Figure 2). The aim is to translate what a customer needs, or the WHATs (vector $\mathbf{w_P}$ in Figure 2), equivalent with the social preferences for agro-landscapes in our application, into strategic or technical requirements or HOWs, i.e. how can these needs be satisfied (vector $\mathbf{w_F}$ in Figure 2), equivalent with the relative priorities of the non-market functions of agriculture in our case study. This is done on the basis of a relationship matrix $\mathbf{W_{F,P}}$ between social preferences (WHATs) and non-market functions

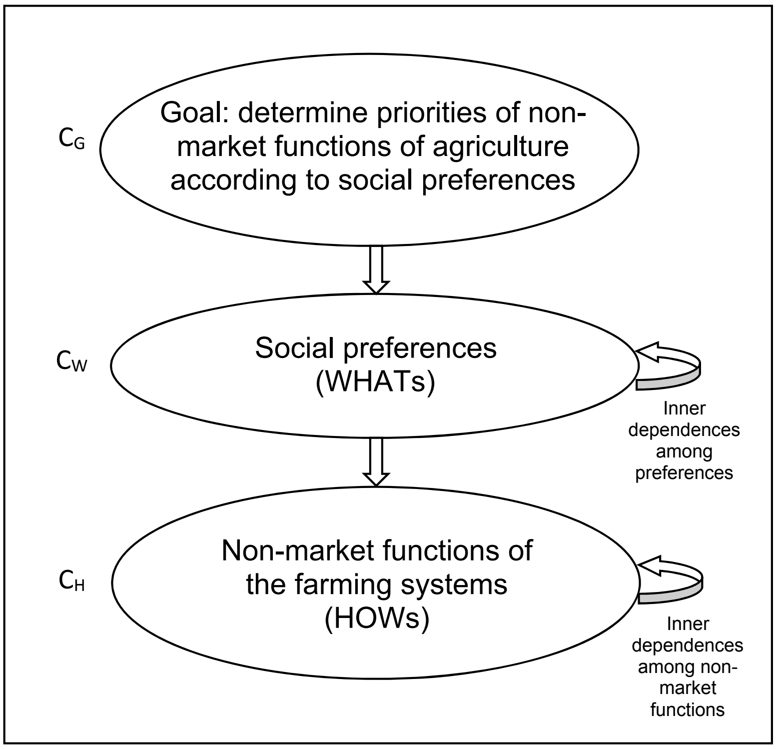
(HOWs). Inner relationships among WHATs ($\mathbf{W_{P,P}}$) and among HOWs ($\mathbf{W_{F,F}}$) may be incorporated in the analysis to fine-tune the results (Partovi, 2006). The matrices of relationships are usually elicited from experts. Shortcomings of the classical application of QFD have been pointed out, and relate to the scale of measurement of the relationships among decisional elements (Wasserman, 1993), and the treatment of inner relationships (Partovi and Corredoira, 2002). Recently it was suggested that the Analytic Network Process provides a scientific basis to overcome these limitations (Partovi, 2001; Partovi and Corredoira, 2002; Karsak et al., 2003; Partovi, 2006).

Figure 2. House of Quality for prioritising non-market functions of agriculture according to social preferences



ANP, Analytic Network Process (Saaty, 1996) is a multi-criteria decision-making tool, which represents a decision problem as a network of components, denoted as elements and clusters of elements, where every element can have an influence on itself or some or all the other elements of the system (Niemira and Saaty, 2004). The ANP representation of a QFD model is shown in Figure 3. Its structure consists of three clusters (after Karsak et al., 2003). The *Cluster of the Goal* (C_G) consists of one element, the final aim of the QFD analysis, in our case to determine the priorities of the agricultural non-market functions according to social preferences. The *Cluster of WHATs* (C_W) consists of the WHATs (social preferences), and the elements of the *Cluster of HOWs* (C_H) represents the HOWs (non-market functions).

Figure 3. Network representation of the House of Quality in ANP



The ANP network is represented in a *super matrix* (Table 1). Each cell describes the contribution of element *i* to the achievement of element *j*, or in ANP jargon, the *dominance* of element *j* over element *i*. This dominance is represented by an arrow from element *j* to element *i* (Figure 3). A cluster is related to another cluster (outer dependence) or to itself (inner dependence) if at least two elements of the cluster(s) are related through a dominance relationship. Outer and inner dependences are the two types of interdependencies among elements. In a QFD network (Figure 3), the cluster of WHATs is dominated by the cluster of HOWs, and each is also inner dependent. To specify the magnitude of the relationships ($w_{i,j}$), WHATs must be evaluated with respect to their contribution to each HOW, WHATs with respect to each WHAT, and HOWs to each HOW. This evaluation is carried out on the basis of *pairwise comparisons* of the relative contributions (or priorities) of the dominated elements in one cluster with respect to the element that dominates them (Saaty, 1980). Dominated elements are compared by pairs, and their relative contribution is calculated once all pairs of elements have been compared. This pair-wise comparison can be done on three different scales: numerical, graphical, and verbal (e.g., Forman and Selly, 2001) and usually involves judgement of experts or stakeholders. ANP provides an algorithm to calculate the vector with the relative contributions of the dominated elements *i* in a cluster to each element *j* (e.g. Saaty, 1994), e.g. the vector of contributions of the functions F1 to F3 to preference P1 $(w_{F1,P1}, w_{F2,P1}, w_{F3,P1})^T$ in Table 1. In this way the so called unweighted super matrix is constructed (see Table 1).

Table 1. ANP super matrix for the proposed QFD model

a) Clusters level

	Goal	WHATs (Preferences)	HOWs (Functions)
Goal	0	0	0
WHATs (Preferences)	$\mathbf{w_P}$	$\mathbf{W_{P,P}}$	0
HOWs (Functions)	0	$\mathbf{W_{F,P}}$	$\mathbf{W_{F,F}}$

b) Elements level

		Goal	WHATs (Preferences)				HOWs (Functions)		
		G	P1	P2	...	P12	F1	F2	F3
Goal	G	0	0	0	...	0	0	0	0
WHATs (Preferences)	P1	w_{P1}	$w_{P1,P1}$	$w_{P1,P2}$	...	$w_{P1,P12}$	0	0	0
	P2	w_{P2}	$w_{P2,P1}$	$w_{P2,P2}$	...	$w_{P2,P12}$	0	0	0
	...	...	...	...	...	...	...	...	...
	P12	w_{P12}	$w_{P12,P1}$	$w_{P12,P2}$	...	$w_{P12,P12}$	0	0	0
HOWs (Functions)	F1	0	$w_{F1,P1}$	$w_{F1,P2}$	...	$w_{F1,P12}$	$w_{F1,F1}$	$w_{F1,F2}$	$w_{F1,F3}$
	F2	0	$w_{F2,P1}$	$w_{F2,P2}$	...	$w_{F2,P12}$	$w_{F2,F1}$	$w_{F2,F2}$	$w_{F2,F3}$
	F3	0	$w_{F3,P1}$	$w_{F3,P2}$	...	$w_{F3,P12}$	$w_{F3,F1}$	$w_{F3,F2}$	$w_{F3,F3}$

To calculate the priorities of the non-market agricultural functions (the HOWs in the general case) a matrix manipulation procedure has been proposed (Saaty and Takizawa, 1986; Lee and Kim, 2000; Karsak et al., 2003; Kahraman et al., 2006). Firstly, the vector of priorities of the social preferences is calculated considering the inner dependencies according to $\mathbf{w_P^{int}} = \mathbf{W_{P,P}} \times \mathbf{w_{P,G}}$. Secondly, the matrix of priorities of the non-market functions as determined by the social preferences is calculated considering the inner dependences among the non-market functions: $\mathbf{W_{F,P}^{int}} = \mathbf{W_{F,F}} \times \mathbf{W_{F,P}}$. Finally, the priorities of the functions considering all the interdependencies are calculated: $\mathbf{w_F} = \mathbf{W_{F,P}^{int}} \times \mathbf{w_{P,G}^{int}}$. A vector $\mathbf{w_F}$ can be obtained for each expert or decision agent (thus we should call it as $\mathbf{w_{F(e)}}$, to refer to the specific expert *e*), being possible to aggregate them as shown in the next section.

In summary, the combination of QFD and ANP methodologies allows to translate the preferences of citizens into priorities of the different non-market functions of the analysed agro-landscapes.

3.2. Prioritizing non-market functions of agriculture in the case study

The set of stakeholders affected by a change in the provision of non-market goods consists potentially of all citizens of the world. However, the impact on different groups could be different depending among others on the spatial proximity to the source of the non-market goods. In this context, the need to properly establish the spatial delimitation of the problem arises: local, national or international level. For practical reasons we consider the Dutch national population, since the impact of the non-market functions of the small analysed region at the international level is considered to be negligible. Demands of Dutch citizens to agriculture are probably not homogeneous and are related to the citizens' proximity to the analysed agro-landscapes. We suppose that the preferences of all Dutch citizens are equally important and thus used the average demand of Netherlands.

Average preferences of Dutch citizens for non-market functions of agriculture were derived from information in the Eurobarometer (EB)[1]. This indicator summarizes opinions and attitudes of European citizens about general and sectorial topics of interest for the European Union, both in a periodical and consolidated manner twice a year (Standard EB), and in an ad hoc manner (Special EB). A Special EB (EC, 2006) deals with perceptions and opinions of citizens in the specific field of agricultural policy. We selected the preferences of Dutch citizens towards agriculture (Table 2), distinguishing twelve categories of preferences (vector $\mathbf{w_P}$). We measure the preferences of citizens through the relative priorities (weights) that they give to different aspect related to the agricultural policy.

Table 2. Preferences of Dutch citizens towards agriculture (EC, 2006)[1]

Aspect	Original priorities	Normalised priorities
P1. Ensure stable and adequate incomes for farmers	36	0.1417
P2. Ensure that agricultural products are healthy and safe	31	0.1220
P3. Promote the respect of environment	24	0.0945
P4. Favour and improve life in the countryside	16	0.0630
P5. Make European agriculture more competitive on world markets	22	0.0866
P6. Protect small or medium sized farms	20	0.0787
P7. Help farmers to adapt their production to consumer's expectations	17	0.0669
P8. Favour methods of organic production	27	0.1063
P9. Reduce development gaps between regions	15	0.0591
P10. Protect the welfare of farm animals	23	0.0906
P11. Encourage the diversification of agricultural products and activities	15	0.0591
P12. Protect the specificity and taste of European agricultural products	8	0.0315
Total	*254*	*1.0000*

[1] http://ec.europa.eu/public_opinion/index_en.htm

This national demand must be translated to the specific functions at the level of the analysed agro-landscape level. We used expert knowledge to describe the outer and inner relationships between Dutch citizens' preferences and the non-market functions of the analysed agro-landscapes as described by the Landscape IMAGES model. Ten experts on sustainable farming systems and with knowledge of the case study situation were interviewed individually following a structured questionnaire. We use average expert assessment which we consider more reliable than individual assessments since it removes individual biases and lack of knowledge on some topics. Such analysis of the mean opinion is common in group decision-making literature (Saaty, 1989). Each of them filled out all correlation matrices, resulting in one super matrix for each expert. Sub-matrices $\mathbf{W}_{F,P}$ and $\mathbf{W}_{F,F}$ were defined according to the pair-wise procedure.

On the contrary, the matrix with relationships between preferences, $\mathbf{W}_{P,P}$, was calculated by direct elicitation (e.g., Larichev et al., 1995; Bottomley and Doyle, 2001). When the number of elements is high as for the social preferences (usually 7-9 is recommended as maximum in ANP; in this case we have 12), the number of pair-wise comparisons can increase excessively, and a 'direct rating' weighting method (Bottomley and Doyle, 2001) is more reasonable. The influence of one element on another was directly elicited using a rating scale, ranging from 1 (very weak relationship) to 9 (very strong relationship). Direct elicitation is equivalent to a rating scale in ANP where scale point 9 is 9/1 times greater than scale point 1, 9/2 times greater than 2, and so on. In the case of no influence of an element *i* on another *j*, a 0 is assigned ($w_{i,j}=0$).

In this way, we obtained one super matrix for each interviewed expert and the associated vector of interdependent priorities of the non-market functions ($\mathbf{w}_{F(e)}$) of the Friesian dairy systems. The individual priorities were aggregated to the group by *Aggregation of Individual Priorities (AIP)* (Ramanathan and Ganesh, 1994), averaged: $\mathbf{w}_{F(group)} = \sum_{e=1}^{G} \mathbf{w}_{F(e)} / G$, where *e* is the expert e, *G* is the number of experts, and $\mathbf{w}_{F(group)} = (w_{F1(group)}, w_{F2(group)}, ... w_{Fn(group)})^T$.

4. Assessment of social net benefits of agro-landscapes

4.1. Market net benefit

Market net benefit is defined as a change in utility for society as result of a change in the equilibrium point in the market of agricultural products. Utility is assumed equivalent to the neoclassical concept of surplus (e.g. Varian, 1999), and can be measured in monetary units. Changes in utility will be measured with respect to the current situation. Assumptions for market net benefit assessment in our case study were:

- Alternative land uses are based on the same fixed inputs as in the current situation, but may require different amounts of variable inputs.
- Prices of inputs and outputs are assumed constant over the short-time horizon considered in the study.

Market net benefit (ΔU_M) is composed of market net benefits of farmers, consumers and government:

- *Market net benefit for farmers* ($\Delta U_{M,FARM}$): The surplus of farmers is the gross margin (GM). Thus, a change in GM is equivalent to a change in utility for farmers, and, since fixed costs are assumed constant, to a change in their profit as producers[2]. So, we have: $\Delta U_{M,FARM} = \Delta GM$; GM=R+S-VC, where *GM* is gross margin, *R* revenue from market, *S* subsidies and *VC* variable costs. In our case study, the market function of agriculture is production of milk.
- *Market net benefit for consumers* ($\Delta U_{M,CONS}$): An approximation of the surplus of consumers for small changes in supply at constant demand curve is (P2-P1)*(Q2+Q1)/2, where *1* and *2* indicate two equilibrium points, and *P* and *Q* the price and the quantity of the product in the market, respectively. Since in the case study price of the output (milk) is assumed constant, that is, it is not affected by a change in the supply, we obtain: $\Delta U_{M,CONS} = 0$.
- *Market net benefit for government* ($\Delta U_{M,GOV}$): Utility for the government increases if support for agriculture decreases. We assume the relation to be: $\Delta U_{M,GOV} = -\Delta S$, where *S* is the public support.

A general relation for market net benefit of a change from the present situation (situation 0) for all stakeholders is: $\Delta U_M = \Delta U_{M,FARM} + \Delta U_{M,CONS} + \Delta U_{M,GOV}$. For our case study this implies: $\Delta U_M = \Delta GM - \Delta S = \Delta R - \Delta VC$.

[2] Surplus of producers equals gross margin. Profit equals gross margin minus fixed costs.

4.2. Non-market net benefit

The non-market functions in our application are landscape quality (F_1=LQ), nature value (F_2=NV) and environmental health (F_3=EH). We define a change in the utility of an agro-landscape for society (dU_{NM}) as:

$$dU_{NM} = \sum_{i=1}^{n} \omega_{Fi} \cdot dF_i / F_i \tag{1}$$

where dF_i/F_i is the change in the non-market function F_i relative to the current performance; ω_{Fi} is the relative importance that society attaches to such a change; and *n* is the number of non-market functions of agriculture. We assume that preferences of society for the non-market functions as determined previously by QFP/ANP refer to the relative weights ω_{Fi}. That is, priorities calculated in section 3.2 for the group of experts, $w_{Fi(group)}$, equal the relative importance that society attaches to each function, ω_{Fi}, as defined in this section. This assumption, and therefore the functional form of Eq. 1, is based on the observation that human beings generally perceive relative change, that is, gains and losses in relation to the level from which the change starts (Lootsma, 1996). It is the result of psycho-physical research on the relationship between the intensities of physical stimuli and sensory responses [Weber's law, Fechner's law, Brentano proposal, and Stevens power law; cited by Lootsma (1996)], and a common assumption in the definition of a practical measure of utility in Economics.

Integrating Eq. 1, the non-market net benefit of a change of agriculture from the present situation (0) to a given situation (s) following a change in its non-market performances results in:

$$\Delta U_{NM} = \sum_{i=1}^{n} \omega_{Fi} \cdot \ln\left[F_i(s)/F_i(0)\right] \tag{2}$$

Our proposal of utility is additive and must satisfy the basic requirements according to the Multi-Attribute Utility Theory (MAUT). Of these conditions, the requirement of additive independence (Keeney and Raiffa, 1976) is the strongest: risk attitude of a person for a given attribute does not depend on the levels of the other attributes (Ananda and Herath, 2005). If components are close to be additively independent, then the simple additive utility function can be applied (Van Calker et al., 2006). In our case, this independence is guaranteed by the implementation of the ANP, which takes interdependencies into account in the calculation of relative priorities of the non-market functions (ω_{Fi}). Moreover, our proposal is additive (sum of components). In an additive functional form it is advisable that $\sum_{i=1}^{n} \omega_{Fi} = 1$ (Ananda and Herath, 2005), as in our case. An additive utility function gives consistent and reliable results if non-linearities in the utility functions are adequately captured (Stewart, 1996), as in our expression (Eq. 2) which is a Cobb-Douglas function. In any case, it has been shown that an additive form should be at least a good approximation of overall value (Kwak et al., 2002), even if aforesaid theoretical conditions are violated (Ananda and Herath, 2005).

4.3. Social net benefit

We define a change of social benefit (dU_S) as:

$$dU_S = \frac{dU_M}{RU_M} + \frac{dU_{NM}}{RU_{NM}} \quad (3)$$

where RU_M and RU_{NM} are the ranges of possible market and non-market net benefits, respectively, for the set of potential agro-landscapes. In Eq. 3, market and non-market net benefits are standardized by these utility ranges (similarly to Qiu, 2005). This implies that improving market performance of the agro-landscape from its worst state to the best one is considered as important as improving its non-market performance from its worst value to the best one.

The social net benefit of a change in the agro-landscape from the present situation (0) to a given situation (s) is obtained by integrating Eq. 3:

$$\Delta U_S = \frac{\Delta U_M}{RU_M} + \frac{\Delta U_{NM}}{RU_{NM}} \quad (4)$$

5. Model-based generation, evaluation and selection of agro-landscape alternatives using the Landscape IMAGES framework

According to OECD (2001a), reconciling food production and environmental goals can sometimes be achieved simply by changing the level, type and location of agricultural production. This section describes how such hypothesis can be tested quantitatively with Landscape IMAGES (Groot et al., 2007), a static modelling and optimizing framework for exploration of the potential contribution of agricultural land-use and landscape management to the improvement of economic and environmental performances at field, farm and landscape levels.

5.1. Exploration methodology

The assessment of the performance of a landscape was based on market (GM) and non-market (LQ, NV and EH) functions. Performance is determined by the arrangement of two types of land-use activities. The first type concerns a field with pasture and its fertilizer and harvesting management regimes. The second concerns the field borders, each of which may or may not contain a hedgerow.

Market and non-market performances may be affected by interaction between land-use activities on two or more spatial units. The allocation of discrete packages of land-use activities (Groot et al., 2007) to the landscape makes the problem of finding the trade-off between the performance criteria 'NP hard': no algorithm exists that guarantees that the exact trade-off surface is obtained under all circumstances, because the dimensionality of the problem, and therefore the computational difficulty, grows faster than any polynomial in the number of decision variables. Heuristic techniques such as genetic algorithms and evolutionary strategies can be employed to obtain approximations of the trade-off surfaces in a population of solutions (Bergey and Ragsdale, 2005; DeVoil et al., 2006; Groot et al., 2007).

In this study we are not only interested in the trade-off between performance criteria, but also in the shape of the solution space to assess both utopia and dystopia. The solution space was explored in three steps: (1) Determination of the extremes for individual performance criteria by single objective optimization; (2) Exploration of the trade-off frontiers between performance criteria by (2a) constrained single objective optimization, followed by (2b) multi-objective optimization; (3) Homogeneous spreading of solutions within the solution space. The subsequent steps use the input of the previous step.

A multi-objective design problem can be generally stated as follows:

$$\text{Max } F(\mathbf{x}) = (F_1(\mathbf{x}),...,F_k(\mathbf{x}))^T \quad (5)$$

$$\mathbf{x} = (x_1,...,x_n)^T \quad (6)$$

Subject to i constraints:

$$g_i (\mathbf{x}) \leq h_i \quad (7)$$

where, $F_1(\mathbf{x}),...,F_k(\mathbf{x})$ are the objective functions that are simultaneously maximized, and $(x_1,...,x_n)$ are the decision variables that represent land use activities allocated to the n spatial units. The decision variables can take on values from a predefined array, $\mathbf{x} \in S$, where S is the solution or parameter space. The problem evolves to a single objective optimization problem when k=1. Constraints (Eq. 7) arise from the problem formulation, for instance by limitations on the inputs or outputs related to the activities.

The evolutionary strategy of Differential Evolution (Storn and Price, 1995) was applied to a population of solutions to improve its average performance criteria generation by generation (Bergey and Ragsdale, 2005). During this iterative process, solutions are selected for each new generation if they perform better than other solutions (for single-objective optimization, in steps 1 and 2a) or on the basis of Pareto optimality or presence in a less crowded area of the solution space (for multi-objective optimization, in step 2b). In step 2a, additional constraints were imposed by setting limits to the non-optimized performance criterion.

In multi-objective optimizations, the solutions can be ranked using the Pareto concept. A set of Pareto optimal solutions consists of solutions that are not dominated by other solutions, when all objectives $F_1(x),...,F_k(x)$ are considered. Ranking of solutions follows the procedure proposed by Goldberg (1989). First the Pareto optimal subset is established. This subset receives the highest rank and is removed from contention. This procedure is repeated, and each next subset receives a lower rank, until all solutions have been ranked. Subsets with higher ranks have an increased probability of being maintained in the next generation. To avoid clustering of solutions and to stimulate spreading of solutions across the trade-off surface, a crowding metric (Deb et al., 2002) was applied. The crowding metric measures the Euclidian distance of a solution to the nearest alternative solution. This metric was used as the only selection criterion in step 3 (with k=2) to homogenize the distribution of solutions within the solution space by maximizing the distances between solutions.

In summary, the exploration methodology allows to define the set of potential production alternatives available in the short term. It gives us information about the potential farming practices available for farmers as well as the economic and environmental impacts of them, which will allow us to detect the best and worst farm practices.

5.2. Application to the case study

An agro-ecological engineering approach was used to design land use activities, which are defined as the cultivation of a crop or vegetation and/or management of a herd in a particular physical environment, completely specified by its inputs and outputs (Van Ittersum and Rabbinge, 1997). Grassland activities including their fertilizer and harvest regimes were allocated to the fields, and field borders could be occupied by a hedgerow or remain unoccupied. The inputs (soil fertility, fertilization level and harvesting regime) and outputs (production of net energy for lactation, species diversity and nutrient emissions) of the land use activities were calculated from established empirical agro-ecological relations. This approach was applied to an area of 232 ha enclosed by roads, comprising three farms with an average area of 42 ha and buffer fields belonging to other land users. Random land-use was allocated to the buffer fields, which were not included in the evaluation of the performance criteria.

The indicator of market performance, landscape gross margin (GM) was calculated as the sum of revenues from milk and animal sales plus subsidies from nature conservation packages minus variable costs. The applicability of conservation packages to individual fields was assessed on the basis of plant species abundance, and harvesting and fertilization regimes. Costs per field were separated into costs related to production (harvesting by grazing or mowing and fertilizer) and transport costs. The revenues were fixed at farm level by the size of the milk quota and the herd size, which was used to calculate the returns from animal sales, with an equation derived from farm data from the dataset used by Groot et al. (2006). The costs at farm level depended on the amount of grass produced on the farm, since the required supplementary feed imports and related costs were calculated from the difference between the amount of milk produced from grass and the allowed production according to the quota. Costs for veterinary care, breeding and contracting were related to quota volume on the basis of farm data (dataset Groot et al., 2006). Farm level constraints were imposed to the proportion of grass dry matter that should be grazed (dependent on the grazing system) and the maximum allowed nitrogen fertilizer application rate (see Groot et al., 2007).

Species abundance in the grass swards and hedge rows was used as an indicator for nature conservation value (NV). The relationship between nutrient availability and average species presence in grasslands was derived on the basis of data of Oomes (1992). Landscape quality (LQ) was described as variation in the landscape and calculated by adding (1) the sum over all fields of the variance of the species number in a field and its neighbours, and (2) the degree of half-openness of the landscape, i.e. 50% of the borders occupied by hedges, calculated as the squared deviation from a completely open or closed landscape (0 or 100% occupation of the borders). Half-openness is seen as a highly typical landscape characteristic in the case area (Renting and Van der Ploeg, 2001). Environmental health (EH) was defined as the avoidance of emission of nutrients, implemented mathematically as the inverse of the emission of nutrients. The emission of nutrients was calculated from the difference between uptake of N by grass and availability of N from natural soil fertility and fertilizer application.

6. Results

6.1. Priorities of the non-market functions for Dutch citizens

The results of expert elicitation are illustrated in Table 3 by the super matrix for expert 01, determined according to the QFD/ANP methodology. The matrices for the other experts are available upon request. After calculating the priorities of the non-market functions of the farming systems in Northern Friesian Woodlands based on each super matrix and averaging, results indicate that 'Environmental health' is the most valued non-market function of the farming systems of the region for Dutch citizens followed by 'Landscape quality' and 'Nature value' (Table 4). These priorities determine the non-market benefit that society may obtain from a change of land use.

Table 3. Example of ANP/QFD super matrix, resulting from the evaluation by Expert 01

		Goal	Social preferences												Non-market functions		
		G	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	F1	F2	F3
Goal	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Social preferences	P1	0.1417	0.1364	0.0877	0.0517	0.1286	0.1081	0.1522	0.0588	0.0000	0.1481	0.0500	0.0000	0.0000	0.0000	0.0000	0.0000
	P2	0.1220	0.1061	0.1579	0.1207	0.1000	0.0811	0.0000	0.1373	0.1515	0.0556	0.0750	0.0270	0.1304	0.0000	0.0000	0.0000
	P3	0.0945	0.0606	0.1404	0.1552	0.0714	0.0000	0.0870	0.0980	0.2424	0.0556	0.1250	0.0541	0.1304	0.0000	0.0000	0.0000
	P4	0.0630	0.0455	0.0526	0.0172	0.1286	0.0270	0.0652	0.0392	0.0000	0.1296	0.0250	0.0270	0.0435	0.0000	0.0000	0.0000
	P5	0.0866	0.1212	0.0351	0.0345	0.0857	0.2432	0.0000	0.1373	0.0000	0.0000	0.0000	0.0811	0.0000	0.0000	0.0000	0.0000
	P6	0.0787	0.0606	0.1053	0.1034	0.1000	0.0270	0.1957	0.0000	0.0000	0.0741	0.0750	0.1081	0.0000	0.0000	0.0000	0.0000
	P7	0.0669	0.1212	0.1053	0.1207	0.1000	0.1892	0.0000	0.1765	0.1515	0.1296	0.1250	0.1081	0.0000	0.0000	0.0000	0.0000
	P8	0.1063	0.0303	0.1228	0.1379	0.0429	0.0000	0.1522	0.0784	0.2727	0.0741	0.2000	0.2162	0.0870	0.0000	0.0000	0.0000
	P9	0.0591	0.1061	0.0526	0.0517	0.0714	0.0270	0.1087	0.0000	0.0000	0.1667	0.0500	0.0811	0.0000	0.0000	0.0000	0.0000
	P10	0.0906	0.0152	0.0000	0.0690	0.0143	0.0541	0.0652	0.0980	0.0909	0.0000	0.2250	0.0000	0.0870	0.0000	0.0000	0.0000
	P11	0.0591	0.1061	0.0877	0.0862	0.1000	0.1892	0.1522	0.1373	0.0909	0.1111	0.0500	0.2432	0.1304	0.0000	0.0000	0.0000
	P12	0.0315	0.0909	0.0526	0.0517	0.0571	0.0541	0.0217	0.0392	0.0000	0.0556	0.0000	0.0541	0.3913	0.0000	0.0000	0.0000
Non-market functions	F1	0.0000	0.0769	0.0810	0.0585	0.3333	0.0000	0.3333	0.3333	0.0572	0.3333	0.0585	0.3333	0.8182	0.7306	0.1488	0.0702
	F2	0.0000	0.4615	0.1884	0.2784	0.3333	0.0000	0.3333	0.3333	0.3458	0.3333	0.2785	0.3333	0.0909	0.1884	0.6908	0.2227
	F3	0.0000	0.4616	0.7306	0.6631	0.3333	0.0000	0.3333	0.3333	0.5969	0.3333	0.6631	0.3333	0.0909	0.0810	0.1603	0.7071

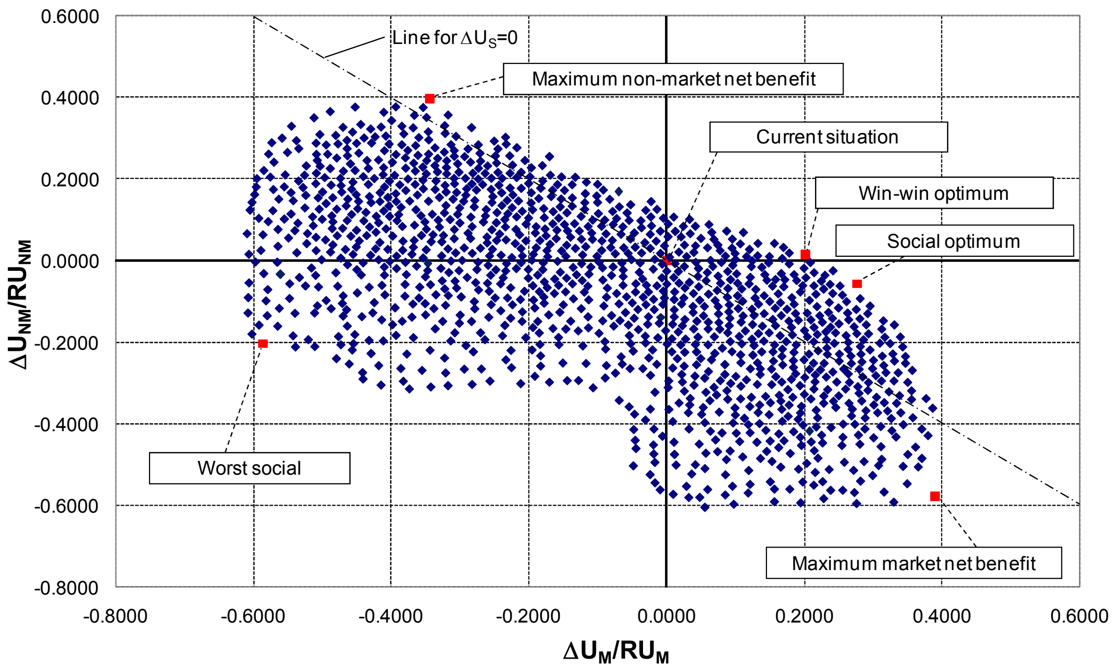
Table 4. Priorities of the non-market functions of agriculture in the case study area integrating Dutch preferences and expert knowledge

Non-market function	Expert code										Mean
	01	02	03	04	05	06	07	08	09	10	
F1. Landscape quality	0.2456	0.3248	0.4207	0.2695	0.2615	0.4164	0.3617	0.2754	0.2688	0.3833	0.3228
F2. Nature value	0.3583	0.3389	0.2522	0.2944	0.1763	0.3561	0.2926	0.2651	0.3321	0.2275	0.2894
F3. Environmental health	0.3960	0.3363	0.3271	0.4360	0.5621	0.2275	0.3457	0.4595	0.3991	0.3892	0.3879

6.2. Market and non-market performances of the production alternatives

Using Landscape IMAGES the entire solution space, defined by relative changes in market and non-market benefits, was revealed. The evolutionary algorithm found 1261 land use alternatives which together approximated the contours of the solution space. Results are shown in Figure 4, where the current situation is placed in the origin of the graph. Points above the line indicating indifference in 'social benefit' (ΔU_S=0, see Eq. 4) represent social gains, and points below this line entail social losses. By imposing restrictions on the desired improvements of market, non-market and social benefits, we selected a number of alternatives that could serve as prototypes of desired or undesired situations of the agro-landscape. These prototypes are indicated in Figure 4, and they are described in the next section.

Figure 4. Market and non-market net benefits for the set of production alternatives and selected prototypes. The dashed line indicates indifference in 'social benefit, i.e. ΔU_S=0 (see Eq. 4)



6.3. Utopian and dystopian landscape prototypes

Our analysis focused on entire prototypes of land use alternatives at landscape level. The prototypes were selected as 'icons' to follow or avoid depending on their particular market and non-market performances. In Figure 5 we show the landscapes of the different prototypes for the case study. In Table 5, the main land use characteristics and the performance of the selected landscape alternatives are summarised.

Figure 5. Landscape prototypes for the analysed region: a. social optimum, b. win-win optimum. c. maximum non-market net benefit, d. current situation, e. maximum market net benefit, f. worst social. Coloured fields belong to the three farms, white fields are buffer fields. Numbers in fields represent the level of fertilizer application (kg N ha^{-1}), thick green lines indicate the presence of hedgerows on field borders

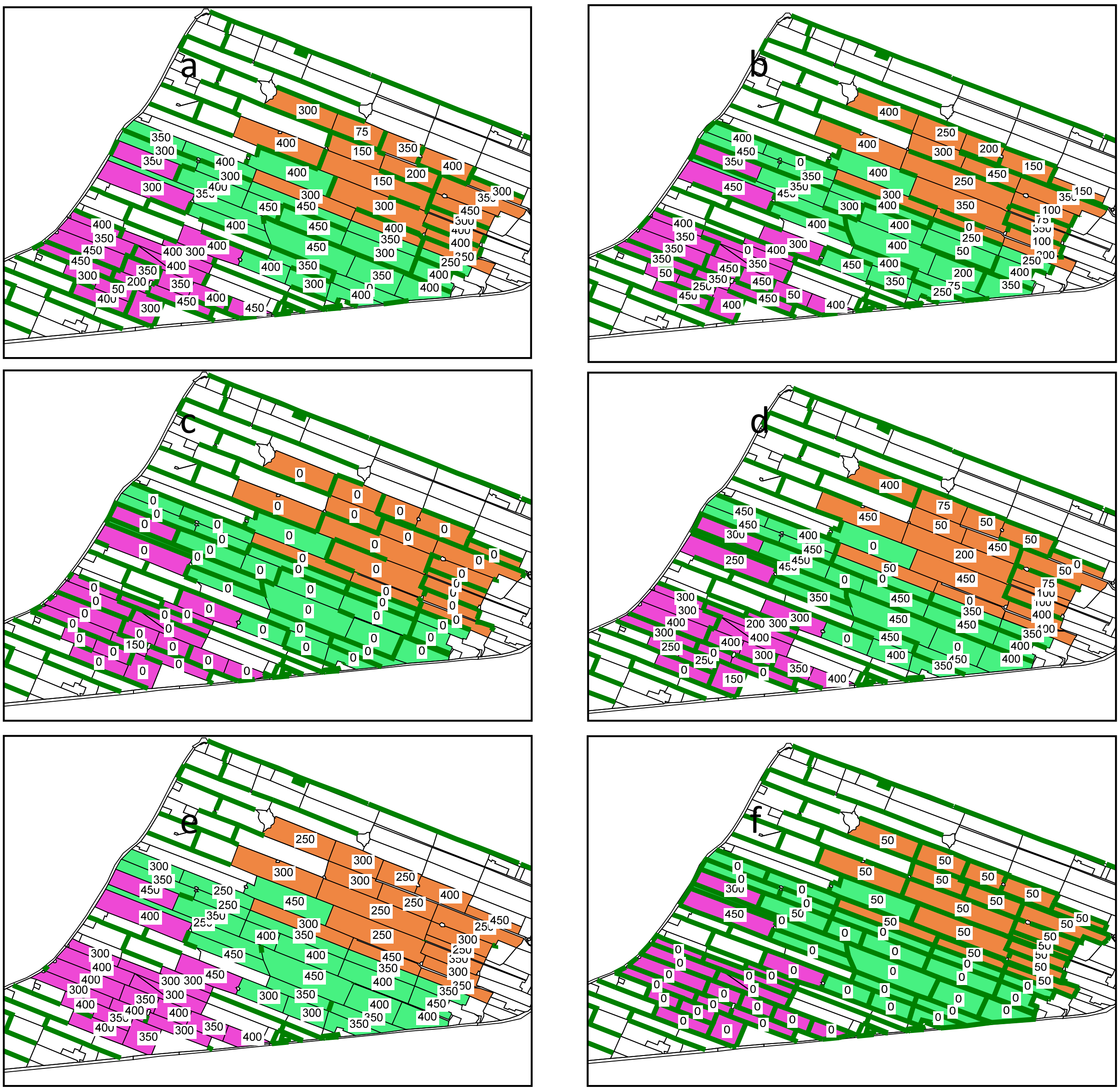


Table 5. Characterisation of the prototypes of farming systems in the case study

Characteristic	Prototype name					
	Social optimum	Win-win optimum	Maximum non-market net benefit	Current situation	Maximum market net benefit	Worst social
Gross margin (€/ha/yr)	2969.08	2947.91	3478.33	2917.43	3024.69	2863.31
Subsidies (€/ha/yr)	33.30	70.68	1029.21	199.59	0.00	603.99
Landscape quality (-)	82.61	122.44	129.04	88.54	0.76	0.70
Nature value (-)	28.25	37.27	103.30	41.28	7.92	144.48
Environmental health (1/(kgN/ha/yr))	0.01	0.01	0.12	0.01	0.01	0.03
$\Delta U_{M,FARM}$ (€/ha/yr)	51.65	30.48	560.90	0.00	107.26	-54.11
$\Delta U_{M,GOV}$ (€/ha/yr)	166.28	128.91	-829.62	0.00	199.59	-404.40
ΔU_{M} (€/ha/yr)	217.93	159.40	-268.72	0.00	306.85	-458.51
$\Delta U_{NM,LQ}$ (-)	-0.0224	0.1047	0.1216	0.0000	-1.5371	-1.5636
$\Delta U_{NM,NV}$ (-)	-0.1097	-0.0295	0.2654	0.0000	-0.4777	0.3625
$\Delta U_{NM,EH}$ (-)	-0.0706	-0.0271	1.0615	0.0000	-0.1043	0.4626
ΔU_{NM} (-)	-0.2027	0.0480	1.4486	0.0000	-2.1192	-0.7386
$\Delta U_{M}/RU_{M}$ (-)	0.2778	0.2032	-0.3425	0.0000	0.3911	-0.5844
$\Delta U_{NM}/RU_{NM}$ (-)	-0.0554	0.0131	0.3957	0.0000	-0.5789	-0.2017
ΔU_{S} (-)	0.2224	0.2163	0.0532	0.0000	-0.1878	-0.7862
Species (per 25 m^2)	8.54	10.47	32.91	14.76	7.35	31.09
Emission (kgN/ha/yr)	170.00	155.23	9.71	144.96	172.41	47.70
N applied (kgN/ha/yr)	342.46	312.82	1.06	266.47	344.36	39.91
Grazing cuts (per yr)	2.07	2.02	1.09	2.44	2.24	3.34
Mowing cuts (per yr)	3.07	2.68	1.77	2.11	2.89	0.21
Occupied border (m/ha)	144.53	181.67	206.83	176.76	5.49	352.84

Note: (-) = dimensionless

The results indicate that the current state of the region is closer to the social optimum than to the socially least preferred prototype (Figure 4). Further approaching the social optimum would involve increasing the market net benefits but slightly decreasing the non-market net benefits of the system. Market net benefit could be increased by a higher gross margin for farmers of almost 2%, even with 83% lower subsidies from agri-environmental schemes. However, non-market net benefit would be decreased since ‘environmental health’, ‘landscape quality’ and ‘nature value’ performances of the current landscape are even slightly beyond social optimum. If we assume that a decrease in non-market net benefit would not be acceptable even when associated with an increase in market net benefit, the search for better alternatives than the current situation is limited to the upper right quadrant of Fig. 4. The socially optimal landscape is then the ‘Win-win optimum’ alternative (Fig. 4), increasing both the market and non-market net benefits of the system. This alternative would represent slightly lower ‘environmental health’ than the current situation and lead to 7% increase in nitrogen emission, and slightly lower ‘nature value’. However, these losses are compensated by the higher ‘landscape quality’ of the system resulting in a higher non-market value.

The ‘Maximum non-market net benefit’ prototype demonstrates the largest changes compared to the current situation, especially for the ‘environmental health’ objective due to a drastic reduction in application and leaching of nitrogen. However, to achieve this requires a substantial sacrifice in terms of market performance of the system. Overall, the change would result in a slight increase of social net benefit.

The ‘Maximum market net benefit’ prototype is characterised by a high application of nitrogen at the expense of a large reduction in non-market net benefit, especially due to a loss in ‘landscape quality’. The absence of hedgerows contributes to this loss of landscape value (Figure 5). Overall the change would entail a negative social net benefit.

The ‘Worst social’ prototype represents dystopia: the alternative with the smallest social net benefit in comparison to the current situation. Each market and non-market indicator would deteriorate except ‘environmental health’ and ‘nature value’. This prototype is characterised by low application of nitrogen and low emission of nitrogen but also low landscape quality and very high subsidies.

7. Discussion

This paper addressed social demand for the multiple functions of agriculture as part of evaluation and design of more sustainable agro-landscapes. The approach set out to answer three subsequent questions: (1) what functions the public want from agriculture, (2) which functions can agriculture supply to the public, and (3) how can public preferences be integrated in the evaluation of agro-landscape performance. Social net benefit was introduced as the indicator which allowed linking the stated preferences in the Eurobarometer to indicators that were evaluated for given agro-landscapes using the agro-ecological landscape model Landscape IMAGES. By using regional preferences, the result of the approach is contextual. The methodology, on the contrary, is broadly applicable and although involving expert opinion, transparent by drawing on the QFD/ANP approach, multi-attribute utility theory and agro-ecological modelling.

In our case study, non-market functions are essentially environmental. Similar relative changes of market and non-market (environmental) benefits thus have the same influence on social welfare. This assumption is in agreement with social demand in Europe: 85% of people in the EU-25 and 75% in the Netherlands think that, on key issues, political decision-makers should pay the same degree of attention to environmental concerns as to economic and social factors (EC, 2005a). Moreover, according to "The Lisbon Agenda" (EC, 2005b) 63% of citizens both in the EU-25 and in the Netherlands give priority to protecting the environment over economic competitiveness, compared to 24% who disagree. Other studies concerned with the multi-attribute sustainability of Dutch dairy farming systems (Van Calker et al., 2006; 2007), using different utility functional forms, elicitation and aggregation methods, obtain similar priorities to our research. Van Calker et al. (2006; 2007) evaluated the preferences of particular groups of stakeholders (producers, consumers, industrial producers, and policy makers) for different economic, social and ecological functions, and aggregate their preferences. Obtained priorities for economic criteria, once normalized, are 0.55, and for ecological plus landscape quality, 0.45.

The results of our study indicate that there is only limited scope for improvement of the current situation in terms of social net benefit (Fig. 4). It may be that the strict environmental policies of the last decade (e.g., Henkens and Van Keulen, 2001) have been effective to reach low inputs and emissions (Table 5; cf. Groot et al., 2006). To satisfy public demand the new challenge appears to be a shift in policy focus to a more landscape-oriented emphasis. Following public demand apparently is not necessarily equivalent to pursuing long-term environmental policy goals. These severe implications of accommodating public opinion should be interpreted with care due to the small scale of the selected case study area as well as due to the choice of case study region where landscape is an important characteristic and farmers have developed high-profile activities to demonstrate their environmental engagement. Application to a larger part of the region and to different regions is desirable. Moreover, the results raise the question how accurate the outcome is in view of uncertainty and variation in inputs and relations. Such uncertainty and variation occurs not only in the definition of public demand, but also among experts on the relation between indicators as quantified in the model and public preferences aimed at the medium and long-term. Uncertainties are inherent to any methodology. The methodology we propose addresses uncertainties by aiming for as much transparency as possible. Uncertainty analysis (Rossing et al., 1994) would yield information on the relation between sources of variation and their contribution to uncertainty in the conclusions. Time series analyses would reveal to which extent the definition of public demand using the Eurobarometer as a proxy, results in consistent recommendations that can be used for consistent policies aimed at the medium and long-term.

A strong point of the methodology is its ability to demonstrate trade-offs between market and non-market benefits of land use alternatives as well as to reveal utopian and dystopian alternatives. The current situation of a landscape consisting of several farms can be compared with alternatives, including the 'social optimum', that is, the land use alternative that maximizes the social value of the landscape given the current technical and agronomic restriction at field and farm scales, and the economic and social environment. The best and worst options can serve as 'icons' to follow or avoid.

The unit of analysis in this study has been the landscape, aggregating market benefits across farms. Farms may differ in their market benefits and aggregation does not address equity among farms, which constitutes an important element for policy design in modern economies. Equity may be addressed by considering market benefits of individual farms or, in larger regions, categories of farms in terms of objectives to be optimized in the multi-dimensional Pareto-objective problem. This increases the dimensionality of the problem and renders the evolutionary algorithm less efficient. Recently, methods to overcome such problems have been put forward by Di Pierro et al. (2005) and Brockhoff and Zitzler (2006). We address this issue of aggregation in more detail in a subsequent paper.

This paper set out to investigate the suggestions of Turner et al. (2000) to assess options for sustainable and welfare-optimizing management and policy using economic valuation, integrated modelling, stakeholder analysis and multi-criteria evaluation as key methodological components. We used Landscape IMAGES and its Pareto-based multi-objective optimization approach as the integrated modelling framework, QFD/ANP to analyze stakeholder priorities and multi-attribute utility theory as a basis for multi-criteria evaluation. The methodology illustrated here at landscape level can also be applied at another level of analysis (field, farm, regional and national) and for other farming systems. The limits of application concern the availability of information on the performance of farming systems at the level and land use of interest. Rather than assessing the monetary equivalents of non-market functions as an input to the assessment, our approach reveals the economic value of non-market functions as a result, expressed as the trade-off between market and non-market net benefits. The economic value of non-market commodities thus emerges as the consequence of the stated preferences of citizens for different functions of agriculture. In view of the methodological objections put forward to various ways of measuring economic value as an input to evaluation, this approach provides an alternative that merits further investigation.

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Artículo 4.

An integrated approach for ex-ante evaluation of public policies for sustainable agriculture at landscape level

[Una aproximación integrada para la evaluación ex-ante de políticas públicas para una agricultura sostenible a nivel de paisaje]

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Abstract

An integrated methodological framework for ex-ante evaluation and planning of public policies for sustainable agriculture at agro-landscape level is proposed. The components of the framework are to: (1) determine the private, i.e. farmers', and public benefits associated to agro-landscapes, consisting of an agricultural land-use system, according to its performance for several market and non-market functions. Market forces determine the market benefits and preferences of society the non-market benefits; (2) explore and select potential sustainable agro-landscapes based on the private and public benefits associated with possible land-use alternatives; (3) define efficient public policy mechanisms for improving social net benefit of agro-landscapes.

The framework is illustrated with a case study in a small dairy farming dominated agro-landscape in The Netherlands, with gross margin, landscape quality, nature value and environmental health as the analysed ecosystem functions. Alternative landscapes consisting of hedgerow configurations and grassland management practices were explored, yielding a set of alternatives representing the solution space in terms of change in private and public benefits. Policy mechanisms were defined to move from the current to a desired landscape based on changes in social net benefits. Moreover, the necessity of a modification in the current agri-environmental support was analysed for each landscape. The analysis considered all farmers in the agro-landscape jointly. The results for the case study showed potential prototypes of landscapes and their performance compared to the current landscape. Extension was the most efficient policy mechanism to promote the change to the socially optimum landscape alternative.

Keywords: Multicriteria analysis; agro-economic modelling; social demands; multifunctionality; landscape.

1. Introduction

In response to the growing awareness of positive and negative effects of agriculture on rural and urban citizens in modern societies other than through commodity production, governments are looking for ways to ensure that non-commodity outputs or externalities of agriculture correspond in quantity, composition and quality to those demanded by society (OECD, 2003). Supplying non-market goods presents particular problems for optimal policy design, not least the elicitation of consumer demand for those goods (Hall et al., 2004). Despite the major implications for rural areas, the configuration of policies seems to have more to do with political expediency than true public preferences (Hall et al., 2004). According to these authors "delivering on growing public demands raises two main questions for farmers and policymakers. First, what might the public actually want? Second, if farmers can deliver on public preferences for non-market goods, how can they be compensated in order to produce the right amount?" (Hall et al., 2004, p.211).

Efforts to address these questions should consider the economic, environmental and social consequences and therefore the sustainability of land-use and agricultural production in an integrated and holistic manner. An overview of scientific approaches at both theoretical and practical levels can be found in Osinski et al. (2003) and in more recent contributions of Van Calker et al. (2006; 2008), Rossing et al. (2007), Van Ittersum et al. (2008), Van Keulen (2007) and Parra-López et al. (2008a).

Economic assessments are usually made through economic valuation methods from Neoclassical Economics and non-monetizing approaches (Farber et al., 2006), whereas for land-use modelling generally non-monetizing valuation or assessment methods are employed (Rossing et al., 2007). The methodologies employed in these approaches include economic valuation, integrated modelling, stakeholder analysis and multi-criteria evaluation. An integrated approach that combines these methodologies could be fruitful in providing complementary insights to improve sustainability and social welfare (Turner et al., 2000). In this paper we apply such an integrated approach as presented by Parra-López et al. (2008b) and extend this with the framework of Pannell (2008) to integrate public and private benefits of different land-use alternatives. The approach results in an estimate of the gain or loss of social benefit of different options and the identification of appropriate policy mechanisms to support the implementation of land-use alternatives that satisfy social demands.

Pannell (2008) distinguishes (1) private net benefits, defined as benefits minus costs accruing to the private land manager as a result of the proposed changes in land management, and (2) public net benefits, which are benefits minus costs accruing to everyone other than the private land manager, that is, all citizens. His framework assumes that the monetary value of the public net benefits is calculable in monetary terms (e.g., € ha^{-1} $year^{-1}$), and therefore is directly commensurable with the value of the private benefits. Depending on the private and public net benefits, different policy mechanisms are proposed to strengthen or discourage the adoption of specific land-use alternatives. Our analysis applies the framework to select from a big range of potential land-configurations over a particular area, rather than comparing competing projects from different areas, which was Pannell's original focus.

In this paper we first summarize and extend the methodology presented by Parra-López et al. (2008b) for assessing benefits of agro-landscapes according to social preferences in (Section 2.1 to 2.3). This framework is stretched further for selection of policy mechanisms at landscape level (Section 2.4 to 2.5). The results of applying this integrated approach to a case study for a small region dominated by intensive, grassland-based dairy farming (described in “Case study” Section 3) are presented in “Results” Section 4 and discussed in “Discussion” Section 5.

2. Methodological framework

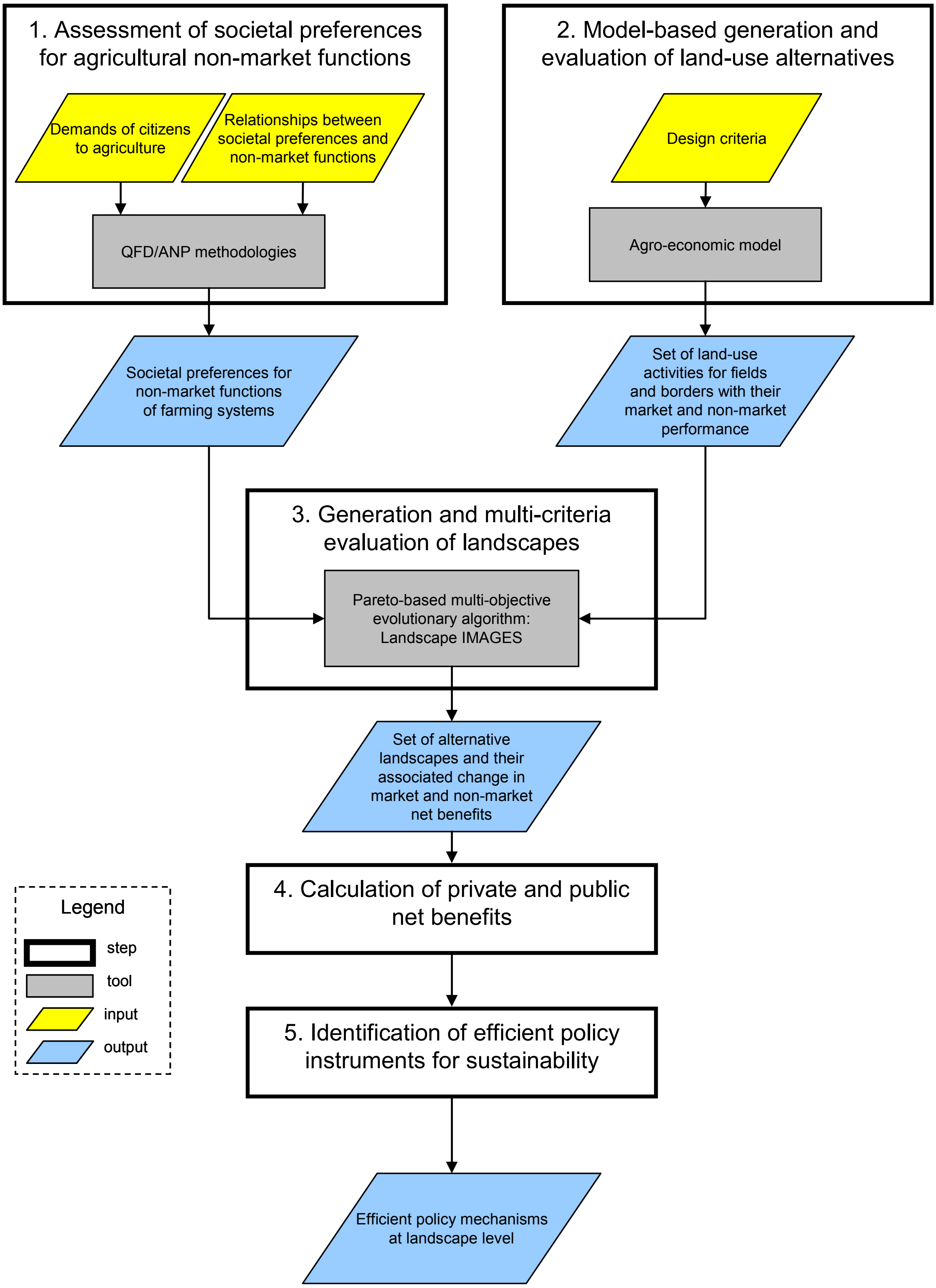
The integrated methodological framework proposed consists of five components (Figure 1). The three first components deal with the integration of the social demand for multifunctionality of agriculture in the evaluation of the performance of rural landscapes, in terms of market and non-market net benefits, following the approach of Parra-López et al. (2008b).

1. Assessment of societal preferences for agricultural non-market functions.
2. Model-based generation and evaluation of land-use alternatives.
3. Generation and multi-criteria evaluation of landscapes: Market and non-market net benefits.

The fourth and fifth components are devoted to the definition and identification of efficient policy mechanisms to favour or avoid changes in farm practices as a function of the private and public net benefits involved, on the basis of the framework of Pannell (2008).

4. Calculation of private and public net benefits.
5. Identification of efficient policy instruments for sustainability.

Figure 1. Schematic representation of the research methodology.



2.1. Assessment of societal preferences for agricultural non-market functions

The combined tools of Quality Function Deployment – QFD (Kogure and Akao, 1983) and Analytic Network Process – ANP (Saaty, 1996) form the core of the analysis of the societal preferences for agricultural non-market functions (Figure 1, component 1). QFD was developed to incorporate the preferences of consumers in the design stage of product planning (Akao, 1997). ANP, a multi-criteria decision methodology, has been proposed to be integrated with QFD to overcome some limitations of traditional implementation of QFD (e.g., Partovi, 2001; Karsak et al., 2003; Parra-López et al., 2008b). The aim of QFD/ANP is to translate what the consumers need or desire (WHATs) into strategic or technical requirements of the production process (HOWs). WHATs in our application are the social preferences for agriculture derived from information in the Eurobarometer (EC, 2006), and HOWs are the non-market functions of agro-landscapes. This is done on the basis of a relationship matrix between the WHATs and the HOWs, and two matrices of inner relationships among WHATs and among HOWs. These matrices are usually elicited from experts. The matrix calculations of QFD/ANP result in a vector ω_{Fi} of priorities of the individual non-market functions F_i of the agro-landscapes (for details see Parra-López et al., 2008b).

2.2. Model-based generation and evaluation of land-use alternatives

The generation and evaluation of land-use alternatives (Figure 1, component 2) was performed with Landscape IMAGES, a static modelling and optimizing framework for exploration of the potential contribution of agricultural land-use and landscape management to the improvement of economic and environmental performances at field, farm and landscape levels (Groot et al., 2007). The model generates a set of solutions, each representing a landscape with a certain allocation of land-use activities on the fields and a configuration of hedgerows on the field borders. Configuration of hedgerows is an important issue in this part of Europe. The assessment of the performance of a landscape was based on market functions (landscape gross margin – GM) and non-market functions (landscape quality – LQ, nature value – NV, and environmental health – EH). For details on these functions see the 'case study' description (Section 2). The performance of the landscape in terms of these functions is determined by the arrangement of two types of land-use activities. The first type concerns a field with pasture and its fertilizer and harvesting management regimes. The second concerns the field borders, each of which may or may not contain a hedgerow. Market and non-market performances may be affected by interaction between land-use activities on two or more spatial units.

For the use of the fields in the landscape we generated production-oriented land-use activities, which are defined as the cultivation of a crop or vegetation and/or management of a herd of livestock in a particular physical environment, completely specified by its inputs and outputs (Van Ittersum and Rabbinge, 1997). The inputs and outputs are fully determined by the physical environment, the plant and animal types and the applied production techniques. Therefore, the production activities were derived from factorial combination of design criteria (Hengsdijk and Van Ittersum, 2002) that explicitly characterize the physical environment (here: soil fertility), types of plants and animals and production techniques (fertilizer application and harvesting regime). An overview of the design criteria and the variants per criterion is given in Table 1. Combinations of variants were filtered for agronomic feasibility. The inputs and outputs (productivity and gross margin, species diversity in fields and hedgerows, and nitrogen losses) of the production activities were calculated from empirical agro-ecological relations.

Table 1. Design criteria and the variants for each criterion as implemented for engineered grassland based dairy farming systems

Attribute	Design criterion	Number of variants
Production environment	Soil fertility	5 levels: 140, 150, 160, 170 and 180 kg N ha^{-1}
Production technique	Fertilizer application	11 levels of fertilizer application: 0, 50, 75, 100, 150, 200, 250, 300, 350, 400 and 450 kg N ha^{-1}
	Harvesting regime	Valid combinations of 0 to 5 grazing periods, 0 to 5 mowing cuts and 3 dates of first harvest (before 1 June, 1-30 June, 1 July or later)

Borders of fields could be occupied by hedgerows. The diversity of plant species in borders occupied by a hedgerow was estimated depending on the land-use intensity on adjacent fields, using the same relations between nitrogen availability and species number as for fields.

The performances of all possible combinations of land-use activities in the landscape constitute the solution space. In this study we are not only interested in the trade-off between the performance criteria, but also in the shape of the solution space to assess both the most and least desirable solutions. Because it is infeasible to enumerate the performance of each combination of land-use activities, we employ heuristic search techniques to approach the contours of the solution space. In this case we applied the evolutionary algorithm of Differential Evolution (Storn and Price, 1997). See Groot et al. (2007) for more details.

2.3. Generation and multi-criteria evaluation of landscapes: market and non-market net benefits

Multi-criteria evaluation of land-use alternatives was performed to assess the social net benefits of agro-landscapes (Figure 1, component 3). Market net benefit (ΔU_M) is defined as a change of the utility of farmers ($\Delta U_{M,FARM}$), consumers ($\Delta U_{M,CONS}$) and government ($\Delta U_{M,GOV}$) as result of a change from current situation in the equilibrium point in the market of the agricultural products originating from the landscape. Utility is assumed equivalent to the neoclassical concept of surplus (e.g. Varian, 1999), and can be measured in monetary units. Market net benefit is measured as:

$$\Delta U_M = \Delta U_{M,FARM} + \Delta U_{M,CONS} + \Delta U_{M,GOV} \quad (1)$$

If prices are constant, as we suppose in our case study (see Parra-López et al., 2008b):

$$\Delta U_M = \Delta U_{M,FARM} + \Delta U_{M,GOV} = \Delta GM - \Delta S \quad (2)$$

where ΔGM and ΔS represent changes relative to landscape gross margin and subsidies, respectively, from current situation as a result of changing management techniques.

Non-market functions of agro-landscapes lack a direct monetary value. In our case study non-market functions are essentially environmental: landscape quality, nature value and environmental health. Parra-López et al. (2008b) proposed to measure the differential non-market net benefit (dU_{NM}) derived from a differential change in the performance in each of the functions, knowing the social preferences, as:

$$dU_{NM} = \sum_{i=1}^{n} \omega_{Fi} \cdot dF_i / F_i \quad (3)$$

where dF_i/F_i is a marginal change in the performance in the non-market function F_i, relative to the current performance; ω_{Fi} (dimensionless) is the priority or value that society gives to a marginal change in the non-market function F_i; and n is the number of non-market functions. Integrating the previous expression we define the non-market net benefit of a change of an agro-landscape from the present situation (0) to a situation *s* as:

$$\Delta U_{NM} = \sum_{i=1}^{n} \omega_{Fi} \cdot \ln\left[F_i(s)/F_i(0)\right] \quad (4)$$

The marginal change in social benefit (dU_S) is defined as:

$$dU_S = \frac{dU_M}{RU_M} + \frac{dU_{NM}}{RU_{NM}} \quad (5)$$

where RU_M and RU_{NM} are the ranges of possible market and non-market benefits, respectively, calculated as the difference between the potentially maximum and minimum benefits. To enable comparisons among economic and environmental indicators Qiu (2005) proposed a similar standardization. This implies the assumption that improving market performance of the agro-landscape from its worst state to the best one is considered as important as improving its non-market performance from its worst value to the best one. This assumption is broadly consistent with social demand in Europe since 85% of people in the EU-25 and 75% in the Netherlands think that, on key issues, political decision-makers should pay the same degree of attention to environmental concerns as to economic and social factors (EC, 2005). Integrating equation (5) from the present situation (0) to a given situation (s), we obtain the definition of the social net benefit (ΔU_S):

$$\Delta U_S = \frac{\Delta U_M}{RU_M} + \frac{\Delta U_{NM}}{RU_{NM}} \quad (6)$$

2.4. Calculation of private and public net benefits

The private and public net benefits, as defined by Pannell (2008), of a change of production alternative can be obtained by regrouping the elements of utility that we obtained (Figure 1, component 4)[1]. Using Eqs. (1) and (4), we can rewrite Eq. (6), defining the social net benefit as:

$$\Delta U_S = \frac{\Delta U_{M,FARM} + \Delta U_{M,CONS} + \Delta U_{M,GOV}}{RU_M} + \frac{\sum_{i=1}^{n} \omega_{Fi} \cdot \ln\left[F_i(s)/F_i(0)\right]}{RU_{NM}} \quad (7)$$

Regrouping terms results in:

$$\Delta U_S = \frac{\Delta U_{M,FARM}}{RU_M} + \left(\frac{\Delta U_{M,CONS} + \Delta U_{M,GOV}}{RU_M} + \frac{\sum_{i=1}^{n} \omega_{Fi} \cdot \ln\left[F_i(s)/F_i(0)\right]}{RU_{NM}} \right) = \Delta U_F + \Delta U_P \quad (8)$$

In this expression, the first term is the farmers' private net benefit, or simply private net benefit, and refers just to market net benefits (from now on ΔU_F). The second term is the public net benefit being the sum of market and non-market net benefits for all citizens (ΔU_P, from now on). Actually ΔU_F refers to farmers as producers, and ΔU_P to society as a whole, including farmers as citizens. In our application, Eq. (8) can be stated as:

[1] In Pannell's original framework, private benefits can include both market and non-market elements. As a first approach to the problem non-market benefits for farmers are not considered, by assuming that market benefits are the basic stimulus for action. That would be something to be dealt with in future work.

$$\Delta U_S = \frac{\Delta GM}{RU_M} + \left(\frac{-\Delta S}{RU_M} + \frac{\sum_{i=1}^{n} \omega_{Fi} \cdot \ln\left[F_i(s)/F_i(0)\right]}{RU_{NM}} \right) \quad (9)$$

2.5. Identification of efficient policy instruments for sustainability

In a context where the multifunctional role of agriculture is recognized, economic and environmental performances of the farming systems must be jointly considered to better define the need for policy. Some general criteria for determining whether there is a case for policy action are (1) whether it is technically possible to replace current farming practices by more environmentally friendly ones and, (2) whether this is economically efficient in the light of the costs and benefits involved (OECD, 2001). The merits of a public investment depend on a broad range of issues, among others: the economic and environmental benefits associated with the change of land-use management practices for land managers and society, the degree of threat the agro-landscapes faces or has already suffered, the technical feasibility of changing the practices, and the adoptability of new practices.

Reconciling food production and environmental goals can in some cases be achieved through the adoption of appropriate technologies. In other cases it can be achieved simply by changing the level, type and location of agricultural production (OECD, 2001). Reconciling food production and environmental and social goals also means that the rights and responsibilities of farmers regarding the adoption of technologies and practices need to be clearly defined and applied, taking into account the current distribution of property rights, and thus the circumstances under which farmers are entitled to remuneration or obliged to pay. Distribution of property rights between farmers and society is a non-trivial issue in the case of non-market outputs. It is widely accepted that farmers should adopt good farming practices to achieve some specific environmental reference levels at their own expense, and that they should be compensated if they are required to achieve an improvement of the environmental performance beyond the reference level or be charged if they fall below this level (e.g., OECD, 2001; Pacini et al., 2004).

Currently in the Netherlands, farmers managing grassland-based systems can subscribe to different subsidy packages from a scheme of agri-environmental support (AES), which aims to attain some defined levels of outputs (e.g., a desired botanical diversity in grassland) by restricting specified inputs (for instance fertilizers or cutting and grazing management). In this study, we accept the rights and duties of farmers and society as established in the current norms of AES as the present implicit sharing of property rights. Here we extend the framework presented in Section 2.1 to 2.3 to evaluate the impact of changes of agricultural land-use and landscape management in the private and public performances of the agro-landscape in the context of current AES. Moreover, we evaluate the convenience of a modification in the AES, and estimate the magnitude of the new support (Figure 1, component 5).

One method for selecting the appropriate policy tools is the use of the cost-effectiveness plane (Campbell et al., 2007). Within this framework, Pannell (2008) suggested a set of basic rules to define appropriate policy mechanisms to favour or avoid changes in farm practices as a function of their private and public net benefits:

1. Do not use positive incentives for change of farming practices unless public net benefits of change are positive.
2. Do not use positive incentives if farmers would adopt farming practices changes without those incentives, that is, if private net benefit is positive. It assumes that if practices are more economically advantageous for farmers and they are aware of it, they will adopt them earlier or later.
3. Do not use positive incentives if private net costs outweigh public net benefits. Rules 1-3 narrow the use of positive incentives area.
4. Do not use extension unless the change being advocated would generate positive private net benefits. The practice should be sufficiently attractive to landholders for it to be 'adoptable' once the extension program ceases.
5. Do not use extension where a change would generate negative public net benefits. Rules 4 and 5 narrow down the extension area.
6. If private net costs outweigh public net benefits, consider technology development to create improved (environmentally beneficial) farm management options that can be made adoptable (with or without positive incentives).
7. If private net benefits outweigh public net costs, the farming practices changes should be accepted if they occur, implying no action. Alternatively, if it is not known whether private net benefits are sufficient to outweigh public net costs, a relatively flexible negative incentive instrument may be used to communicate the public net costs to land managers (e.g., a pollution tax), leaving the ultimate decision to the land managers. Inflexible negative incentives, such as command-and-control, should not be used in this case.
8. If public net costs outweigh private net benefits, use negative incentives.
9. If public net benefits and private net benefits are both negative, and landholders accurately perceive this, then no action is necessary. Adverse practices are unlikely to be adopted. If there is concern that landholders have misperceptions about the relevant land uses, adoption of environmentally adverse practices could be discouraged by extension, or more strongly by negative incentives.

With these rules different 'regions' of efficient policy mechanisms can be identified, which are characterized in Table 2.

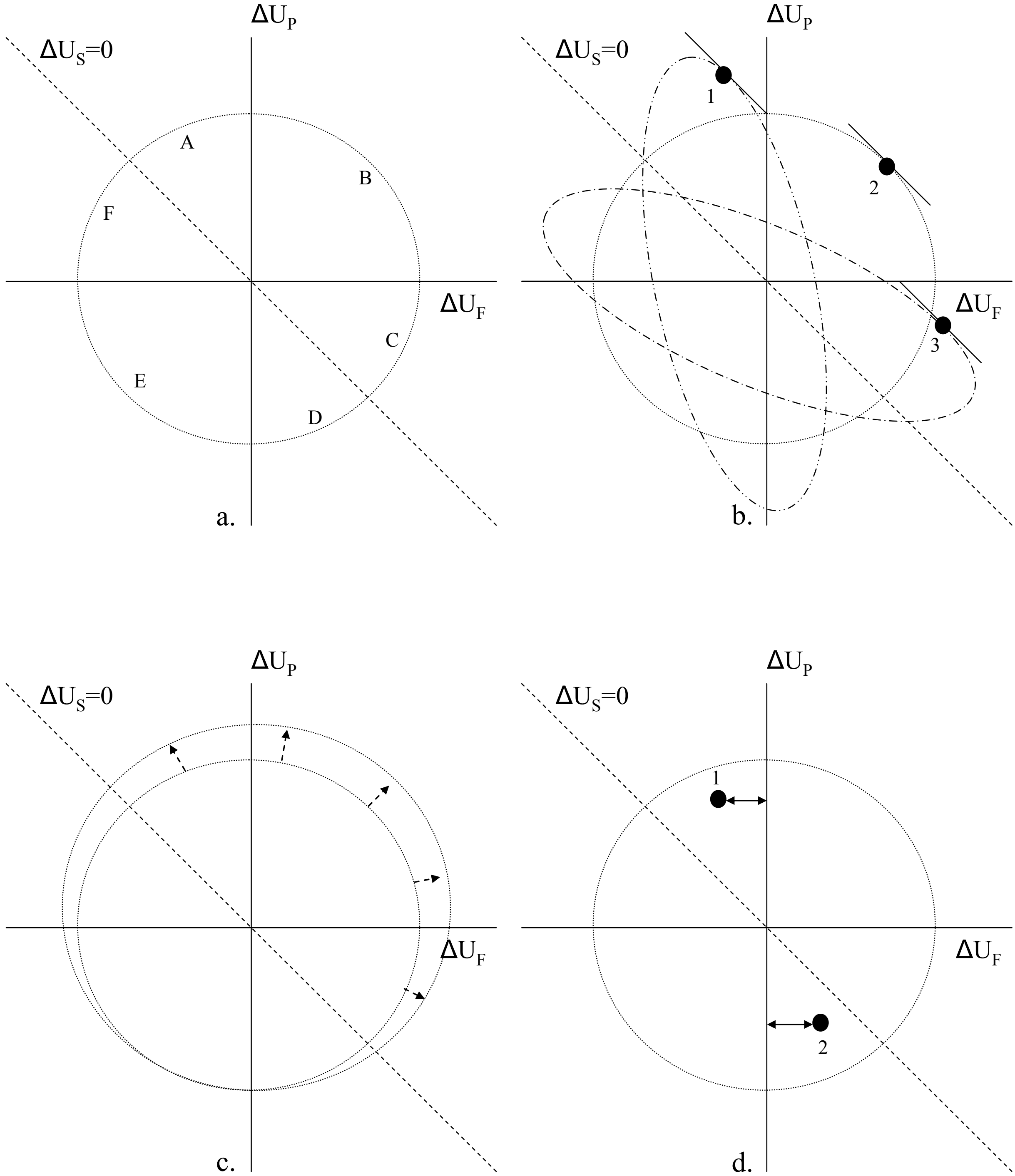
Table 2. Categories of policy mechanisms at landscape level

Category	**Mathematical delimitation**			**Policy mechanism**
	U_F	**U_P**	**U_S**	
(A) Positive incentives	0	0	0	Financial or regulatory instruments to encourage change
(B) Extension	0	0	0	Technology transfer, education, communication, demonstrations, support for community network
(C) No action (or flexible negative incentives)	0	0	0	Informed inaction
(D) Negative incentives	0	0	0	Financial or regulatory instruments to inhibit change
(E) No action (or extension or negative incentives)	0	0	0	Informed inaction
(F) Technology development (or no action)	0	0	0	Development of improved land management options, such as through strategic R&D, participatory R&D with landholders, provision of infrastructure to support a new management option

Based on Pannell (2008).

These regions are visualized in Figure 2a, in relation to the changes in private and public benefit associated with the full set of land-use alternatives at landscape scale, in this paper calculated using the Landscape IMAGES model (Section 2.2). The contour of the solution space is represented as a circle in Figure 2a, and contains a discrete set of alternative landscapes. The performance of the landscapes under changed management is plotted relative to the current situation, which is situated in the origin of the graph. Points located on the line for ΔU_S=0 represent alternatives with the same social value as the present situation. Points to the right of this line entail an increase of social net benefit (ΔU_S>0) and those to the left entail a loss (ΔU_S<0).

Figure 2. Efficient policy mechanisms on the basis of farmers and public net benefit. For more explanation see Table 2 and text. (a) Different policy mechanisms in the regions A to F in the solution space. (b) Two solution spaces with contrasting shapes, with the social optimum for each indicated by points 1, 2 and 3. (c) Change in the shape of the solution space due to technological development. (d) Incentives to encourage or discourage adoption of different positions in the solution space, indicated by the distance of points 1 and 2 to the Y-axis. Based on Pannell (2008).



The shape of the solution space is represented by ellipses in Figure 2b and 2c for illustration, but can take on any shape. The shape depends on the technical possibilities and existing policies at the time of the assessment, and reflects the current bio-physical conditions for farming that determine the response of production to inputs, the available technical means and inputs and the available subsidy schemes. Moreover, the shape of the solution space can change in the future by bio-physical processes (e.g., erosion, soil fertility loss), and technological and policy developments (Figure 2c). The land-use option within the set of feasible alternative landscapes that maximises the social benefit is the 'social optimum' point. This point is the most outward point of the solution space when moving a line parallel to the line for ΔU_S=0 to the top right corner of the graph. This point can be located in the regions of 'positive incentives', 'extension' and 'no action' as policy mechanism (points 1-3 in Figure 2b).

Policy mechanisms do not consist only in the assignation of positive and negative incentives to farmers through subsidies and taxes, but also private and public initiatives to facilitate the diffusion of appropriate farming practices. For instance, extension (e.g., education, technology transfer and communication) is a relatively cheap policy mechanism that helps landholders to learn about the available land management practices, including practices that environmental managers would like to see adopted (Pannell, 2008). Technology development means development of improved land management options, such as through strategic R&D, participatory R&D with landholders, and perhaps provision of infrastructure (Pannell, 2008).

Starting from existing incentives associated with each land-use combination according to the current AES scheme, that are accounted for as part of the market benefit of farmers, an extra support (ES) is calculated according to the private (for farmers) and public performance of the landscape and societal preferences[2]. The extra support can be interpreted as a correction of current incentives after considering social demand for agriculture. Therefore incentives for farmers are the addition of current subsidies according to the AES scheme and extra support. Extra support can be positive, usually consisting of subsidies to facilitate the diffusion of appropriate farming practices, or negative, such as taxes to restrain diffusion of inappropriate practices. The monetary value of the extra support needed to encourage or inhibit the change from the present situation can be calculated for regions A and D in Figure 2a. Since alternatives in region A increase social net benefit, but ΔU_F is negative, it is possible to compensate the farmers that want to change to these alternatives by extra support. For region D social net benefit decreases but ΔU_F is positive, and extra support aims to penalize change. The amount of

[2] In Pannell's original framework, subsidies (or other government costs) are not included in calculations. In our application we explicitly consider current subsidies as part of farmers' private and public benefits. The calculated extra support (ES) is therefore equivalent to the incentives in Pannell's original framework.

extra support needed can be considered as a variation of the current support: $ES=-\Delta U_{M,FARM}=-\Delta GM$ (points 1 and 2 in Figure 2d). Thus, ΔU_S is maintained but part of the social benefit (ES/RU_M) is transferred from farmers to citizens (Figure 2d, point 1) or from citizens to farmers (Figure 2d, point 2) as compensation. Net benefit for farmers after the application of the extra support will be null. Thus, adoption of alternative farming systems that entail increasing social net benefit is favoured while those decreasing social net benefit are avoided. Therefore, recommended new support (NS) for alternative agro-landscapes in regions A and D is NS=S+ES, where S is the current level of support at the landscape level.

3. Case study

The Northern Friesian Woodlands (The Netherlands) is a region characterized by a small-scale landscape on predominantly sandy soils with dairy farming as the prevailing land-use activity. On some farms a limited proportion of up to 5% of the area is used for forage maize production, while the rest of the area is occupied by permanent grassland, rotationally grazed and mown. The fields with an average size of 2 ha are often surrounded by hedgerows and frequently border on ponds. The average grazing season lasts 6 months from May to October. Grazing systems range from day and night grazing to restricted and zero grazing. The bio-physical farm and field characteristics and the social demands as articulated in regulations to maintain landscape and land-use have limited the possibilities to convert to large scale agriculture in the past. On the other hand, the region offers ample opportunities to provide non-productive amenities, and the financial benefits from exploitation of these amenities contribute to sustaining farming in the area (Berentsen et al., 2007).

In this paper we will explore opportunities to satisfy both the non-market and the market functions of the agro-landscape by adapting agricultural land-use and land management in an area of 232 ha, comprising three farms. As the indicator of the market function we use landscape gross margin (GM), which is defined as the total revenues minus all variable costs, at the landscape scale. Additionally, individual farm gross margins are used for policy design at farm level. Furthermore, three key non-market functions supported by the activities of local environmental cooperatives were analysed:

F4. Landscape quality (LQ): This function refers to variation in number of plant species in pastures and to irregularity in the hedgerow pattern, referred to as half-openness of the landscape. This function pertains to the spatial scales of field and landscape.

F5. Nature value (NV): This function refers to high species diversity in the grass swards and hedgerows (number of species per ha) and is relevant at the field scale.

F6. Environmental health (EH): Low nitrogen loss from agriculture, here also interpreted at the field scale.

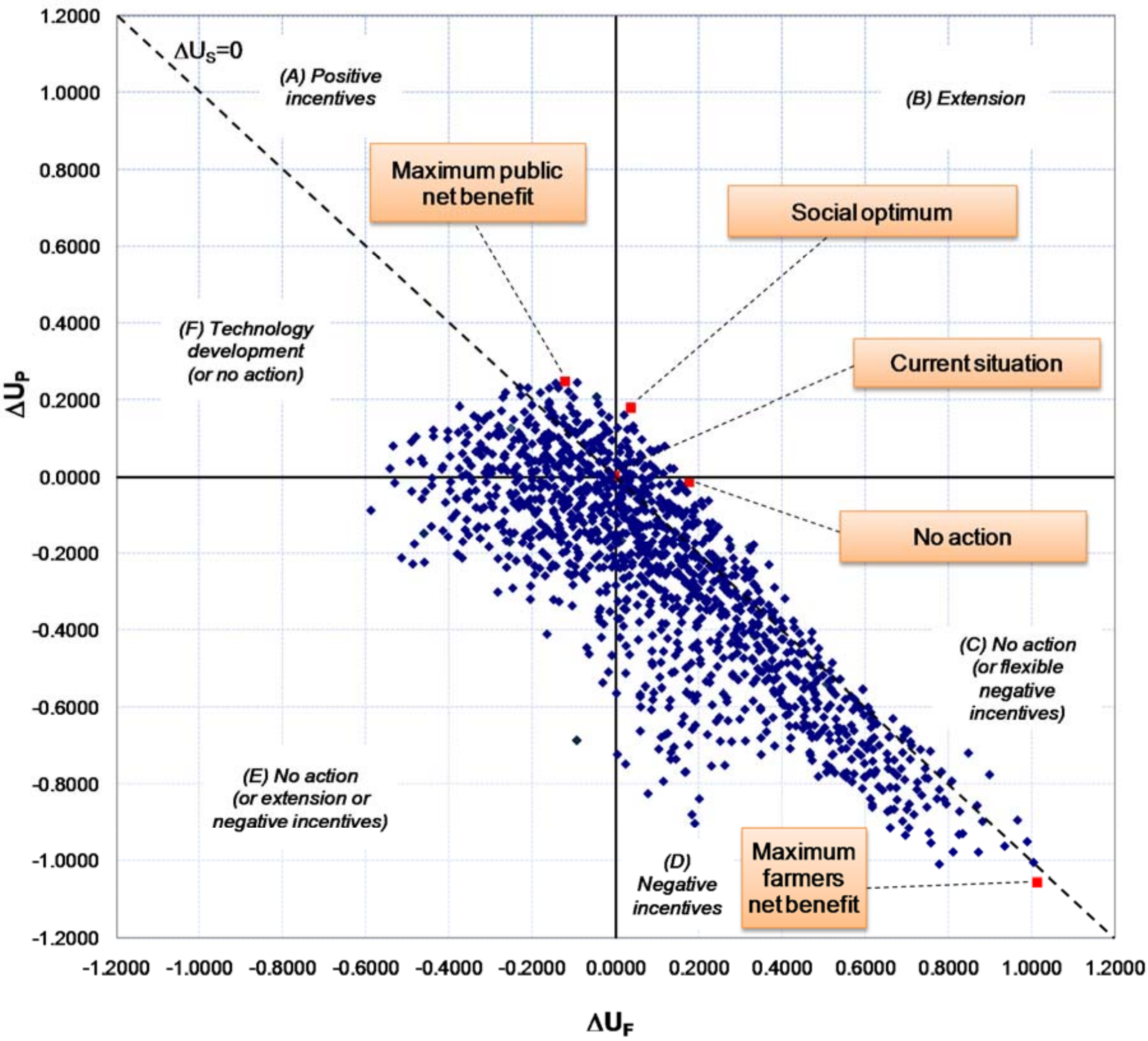
Parra-López et al. (2008b) calculate the priorities of these non-market functions of the Friesian dairy systems according to preferences of Dutch society from agriculture and technical knowledge of experts. According to these results, 'environmental health', defined as the reciprocal of nitrogen loss, is the most important non-market function ($\omega_{EH} = 0.3879$). This is followed by 'landscape quality', which represents the variation in species numbers in grassland fields and irregularity in the hedgerow pattern ($\omega_{LQ} = 0.3228$). 'Nature value' indicating species abundance in the grass swards and hedgerows is the less important ($\omega_{NV} = 0.2894$). This prioritization has been used to evaluate the non-market benefits of the agro-landscapes in this paper (see Section 2.3).

4. Results

4.1. Private and public benefits of alternative landscapes

A set of 1261 alternative agro-landscapes was generated with the Landscape IMAGES framework. The multi-criteria evaluation methodology allowed joint estimation of the market and non-market net benefits of a change from the current farm and landscape situation and the private and public net benefits of this change. The analysis determines the social net benefit of each potential change and therefore provides an indicator of its desirability. In Figure 3, farmers' private net benefits and public net benefits are represented for the set of generated alternative agro-landscapes. The current situation is located at the origin and changes are measured relative to this point. The potential landscape alternatives differ considerably in the benefits produced for farmers and the public. In addition, options for increasing social benefit (above the dashed diagonal line) are fewer than those that will decrease it (Figure 3).

Figure 3. Farmers' private and public net benefits from current situation, selected prototypes in Northern Friesian Woodlands and categories of landscape policy mechanisms. See Figure 2a and Table 2.



4.2. Land-use alternatives and policies at landscape level

From the set of landscape alternatives, it is possible to select specific prototypes to follow or avoid given their particular performances in terms of ΔU_F, ΔU_P, and ΔU_S. The X- and Y-axis, and the line for ΔU_S=0 in Figure 3 delimit the regions of efficient policy mechanisms for the case study, as defined in Table 2 and Figure 2a.

The alternative that maximises the social net benefit, indicated as the 'social optimum' point (Figure 3), is determined by the line parallel to and to the right of ΔU_S=0, tangent to the set of alternatives[3]. The social optimum entails positive public benefits (ΔU_P=0.1773 in Table 3) and positive farmers' private benefits (ΔU_F=0.0389), and therefore an increase in the social benefit (ΔU_S=0.2161). Further approaching the social optimum would involve increasing the landscape quality but slightly decreasing the nature value and environmental health of the landscape ($\Delta U_{NM,LQ}$, $\Delta U_{NM,NV}$ and $\Delta U_{NM,EH}$, respectively, in Table 3). Gross margin of farmers would be increased around 1% even with 65% lower subsidies from agri-environmental schemes (see Table 3). This alternative is located in the region where 'extension' is the efficient policy mechanism (region B in Figure 2a and Table 2). Extension is effective to achieve adoption of the changes in land-use practices needed without any extra support because the private net benefits of adoption are positive. The appropriate policy to promote the change should be based on technology transfer, education, communication, demonstrations, support for community networking, etc.

Apart of the social optimum, other landscape alternatives may be selected to be targeted by public authorities. Such selection might be based on the availability of public resources for support, 'ideological' preferences of policy makers, etc. For illustrative purposes about policy implications, not covered in the other analysed alternatives, we have selected one 'no action' alternative that would improve social net benefits located in region C of Figure 2a. This alternative is characterized by a positive change in social benefit (ΔU_S=0.1636). It could be reached without policy intervention since the increase of private benefits (ΔU_F=0.1783) stimulates farmers to change. Extension to create awareness of the benefits of change is not appropriate since the public benefits would decrease (ΔU_P=-0.0147) due to poor environmental performance, as reflected in decreases in landscape quality ($\Delta U_{NM,LQ}$), nature value ($\Delta U_{NM,NV}$) and environmental health ($\Delta U_{NM,EH}$) (Table 3). Even flexible negative incentives would be appropriate.

The 'maximum public net benefit' landscape is associated with the highest public benefit (ΔU_P=0.2447) since all environmental indicators would be improved. Farmers, however, suffer a decrease in benefit (ΔU_F=-0.1198). Because the decrease is smaller in absolute terms than the increase in public benefit, society would gain by the change. The most efficient policy mechanism to stimulate this change would be 'positive incentives', which would compensate the losses of farmers with an extra support ES of 94.01 € ha^{-1} $year^{-1}$.

[3] In Pannell's original framework the benefit-cost ratio (BCR) of public investment is maximized, by considering public benefits and costs. Other possible criteria could be maximize public benefits, maximize social benefits, maximize the ratio social benefits-public support, minimize costs, etc. Here we propose to maximize the 'social net benefit' (ΔU_S). This indicator aggregates public and private benefits weighted according to social preferences (see section 2.4).

Table 3. Characteristics of the current landscape in the Northern Friesian Woodlands and optimal landscapes associated with the policy mechanisms proposed by Pannell (2008)*

Characteristic**	Alternative agro-landscapes				
	Current situation	Social optimum	No action	Maximum public net benefit	Maximum farmers net benefit
Gross margin - GM (€ ha^{-1} $year^{-1}$)	2917.43	2947.91	3057.33	2823.42	3714.13
Current support - S (€ ha^{-1} $year^{-1}$)	199.59	70.68	72.80	85.17	1136.68
Landscape quality - LQ (-)	88.54	122.44	39.13	114.42	16.60
Nature value - NV ()	41.28	37.27	13.20	58.65	42.56
Environmental health – EH (kg N^{-1} ha year)	0.0076	0.0071	0.0066	0.0121	0.1089
$\Delta U_{M,FARM}$ (€ ha^{-1} $year^{-1}$)	0.00	30.48	139.90	-94.01	796.70
$\Delta U_{M,GOV}$ (€ ha^{-1} $year^{-1}$)	0.00	128.91	126.78	114.42	-937.09
ΔU_{M} (€ ha^{-1} $year^{-1}$)	0.00	159.40	266.68	20.41	-140.39
$\Delta U_{NM,LQ}$ ()	0.0000	0.1047	-0.2635	0.0828	-0.5403
$\Delta U_{NM,NV}$ ()	0.0000	-0.0295	-0.3300	0.1016	0.0088
$\Delta U_{NM,EH}$ ()	0.0000	-0.0271	-0.0579	0.1809	1.0320
ΔU_{NM} ()	0.0000	0.0480	-0.6514	0.3653	0.5005
$\Delta U_{M}/RU_{M}$ ()	0.0000	0.2032	0.3399	0.0260	-0.1789
$\Delta U_{NM}/RU_{NM}$ ()	0.0000	0.0130	-0.1763	0.0989	0.1354
ΔU_{F} ()	0.0000	0.0389	0.1783	-0.1198	1.0155
ΔU_{P} ()	0.0000	0.1773	-0.0147	0.2447	-1.0590
ΔU_{S} ()	0.0000	0.2161	0.1636	0.1249	-0.0435
Policy mechanism at landscape level	-	Extension	No action (or flexible negative incentives)	Positive incentives	Negative incentives
Extra support - ES (€ ha^{-1} $year^{-1}$)	0.00	0.00	0.00	94.01	-796.70
New support - NS (€ ha^{-1} $year^{-1}$)	199.59	70.68	72.80	179.18	339.98

** For explanation of characteristics see text; ** () = dimensionless*

Finally, in the landscape associated with 'maximum farmers net benefit' public loss (ΔU_P=-1.0590) slightly surpasses private benefit (ΔU_F=1.0155) in absolute terms, resulting in a decrease of social benefit. Negatives incentives should be used as policy mechanism to dissuade farmers to follow this alternative. This is achieved by transferring their private benefit to society through a negative extra support ES of 796.70 € ha^{-1} $year^{-1}$.

5. Discussion

Land-use policy planning for multifunctional and sustainable agriculture can benefit from an integrated approach (Mattison and Norris, 2005) that combines economic valuation, integrated modelling, stakeholder analysis, and multi-criteria evaluation. In this paper, an integrated methodological framework for policy planning in agro-landscapes has been proposed. It combines multi-criteria valuation of public preferences for multifunctionality of agriculture, integrated agro-economic modelling and optimizing, and policy analysis. The aim was to analyse the supply and social demand of multiple functions of agriculture, including market and non-market goods and services, and consider it in the evaluation and planning of public agricultural policies. The approach identified agro-landscapes consisting of multiple different farming systems and associated ecological infrastructure that estimate private and public net benefits, and helped determine the public policy mechanisms most appropriate for stimulating/avoiding a change from the current situation towards the more socially desirable/undesirable landscapes.

The framework takes as given the existing agri-environmental support (AES) scheme. Rights and duties of farmers and society as established in the current norms of AES are accepted as the present implicit sharing of property rights. This existing scheme aims to attain some defined levels of outputs and inputs although there is considerable controversy about whether these levels are really achieved. The framework presented in this paper proposes a modification in the AES to really achieve objectives of society regarding the functions of the analysed landscapes. The appropriateness of a quantitative and qualitative modification of the current AES scheme is evaluated on the basis of the expected/modelled environmental and market benefits of each land-use management option. A quantitative modification would be a change in the magnitude of 'monetary' public support, and a qualitative modification would be the use of alternative and potentially useful 'non-monetary' policy mechanisms. Policy mechanisms available are diverse, including positive incentives and negative incentives, but also knowledge accumulation and dissemination (extension, technology development), and informed inaction. Selection of efficient policy tools depends on the extent to which a private land management practice results in public benefits. One method for selecting the appropriate policy tool is the use of the cost-effectiveness plane (Campbell et al., 2007). This approach has been used in a number of different policy arenas where a mix of public good and private good benefits exists (Campbell et al., 2007), including health (Willan and Briggs, 2006), water resource management (Grafton, 2007) and land management (Pannell, 2008).

The results for the case study in Northern Friesian Woodlands in The Netherlands showed potential prototypes of landscapes and their performance compared to the current landscape. Among the alternatives the socially optimum landscape demonstrated the highest social benefit. Extension was the most efficient policy mechanism to promote the change to this alternative from the current situation. Extension should focus in the promotion of the adoption of the land-use alternative that maximises social net benefit, that is, the 'social optimum' alternative. In practice, it may also occur that farmers will attempt to pursue the option that maximises their private net benefit, and if private net benefits outweigh public net costs, the farming practices changes should be accepted, implying no action and a small loss of social net benefit. Alternatively flexible negative incentives may be used. However, our interest is to define efficient public policy instruments towards sustainable agriculture that maximise social welfare, and therefore public support should focus on the promotion of the 'social optimum' alternative.

The results also indicate that for the analysed region there is only limited scope for improvement of the current situation in terms of social net benefit. It may be that the strict environmental policies of the last decade (e.g., Henkens and Van Keulen, 2001) have already been effective in promoting low inputs and emissions. To satisfy public demand the new challenge appears to be a shift in policy focus to a more landscape-oriented emphasis (Parra-López et al., 2008b). Criteria other than social benefit could be used to select the most desirable landscape, and could therefore also affect the most efficient policy mechanism to be selected to reach the desired landscape and land-use configuration. Examples of other criteria may include maximization of the benefit-cost performance of the alternatives, minimization of costs, etc. In practice, support may be conditioned by the availability of resources or ideological preferences of policy makers or influential stakeholder groups, etc. In any case, the criteria should be made explicit, since adoption of new policies and transition between policies is often retarded or obstructed by economic legacies or for political reasons such as the nurture of existing policies (Harvey, 2003).

The identification of the desired future landscape and selection of appropriate policy tool is done relative to the current situation in terms of biophysical conditions, technological development and existing policies that determine the solution space, and the current societal demand for ecosystem services. Both aspects are dynamic and prone to uncertainties, whereas the realization of the selected plan will demand a long-term effort to enable the biological system to adjust to new management practices and eventually provide the anticipated services. Therefore, the framework as developed in this paper should be embedded in an adaptive policy development approach (Walker et al., 2001) that employs a continuous, iterative process of goal-oriented adaptive development (Von Wirén-Lehr, 2001; Rossing et al., 2007), constituting steps of monitoring of changes in the agro-ecosystem and developments in society (observation) followed by a new round of design, selection of desirable landscapes and appropriate policies, and planning. The Landscape IMAGES approach generates innovative farming and land-use systems that in some cases proved superior to the current situation, for instance the configuration labelled 'maximum farmers net benefit' in Figure 3 that, despite its obvious desirability from the farmers' perspective, has not been realized by the farmers in the current situation. Thus, the methodology helps to explore the attainable future alternatives to inform the stakeholders involved such as farmers or non-governmental organizations for landscape management, to support their discussions and decision-making processes.

Transaction costs associated with a policy mechanism can have an impact on its economic efficiency. Moreover, it is an assumption of the applied framework that private net benefit operates as the driving force for farmers' decisions, as in the basic version of Pannell's proposal (Pannell, 2008). Specifically, in our proposal only market benefit of farmers are considered, as a first approach to the problem. In this context, the 'optimum' alternative for farmers may not be the 'maximum farmers net benefit' if we consider significant the costs and benefits for farmers other that the strictly monetary. In fact, Pannell refines his basic theoretical framework to incorporate some other costs to account for lags to adoption, learning costs, and transaction costs (Pannell, 2008). This results in a redefinition of the shape of the 'policy regions' in Figure 2a and Figure 3, and requires some additional assumptions to estimate these 'non-monetary' costs. This paper makes use of the basic framework proposed by Pannell, and more specifically, only market benefit of farmers are considered; refinements are possible to apply his more complete framework but remain for future research.

The implemented model has been developed as a static model of decision-making in the short term. In the case of a time horizon long enough to allow changes in prices it would be necessary to build a series of static models for different moments in time. It would yield different sets of landscape alternatives as time evolves. Similarly, if prices can no longer be assumed to be exogenous, a partial equilibrium approach would need to be put in place. This would make the model more complex, but the approach would basically remain the same.

Since many biodiversity and landscape services are only relevant at scales beyond the single farm but the farm is the basic unit of decision making the 'real' effectiveness of the proposed policy mechanisms would be favoured if the farmers act together with a common interest, supported by effective institutional arrangements and social capital (cf. Pretty et al., 2001; Pascual and Perrings, 2007; Sick, 2008). These arrangements could contribute to improved equity in agricultural areas, which has been proposed as one of the key attributes of sustainable development (Okey, 1996). Although it has been not analysed in this study, an important purpose of these socio-institutional innovations could be to reduce transaction costs for the implementation of policies (Vatn, 2002). Decentralized governmental, non-governmental and farmers' organizations should take responsibility for implementation, administration and monitoring of landscape plans (Pretty et al., 2001). A firm basis for effective institutional arrangements is observed in so-called environmental cooperatives that are well-established in the case study area of the Northern Frisian Woodlands (Renting and Van der Ploeg, 2001). Recently, several environmental cooperatives in this area have merged to create a regional cooperative, which aims to establish contracts with the Dutch government wherein the participating farmers are rewarded or punished as a group for succeeding or failing to reach environmental objectives (Anonymous, 2005). Initially, these objectives focused on reduction of nutrient losses at regional scale, but gradually more attention is being paid to development of ecosystem services related to biodiversity and landscape. For further research it would be valuable to analyse the economic effectiveness and social consequences for sustainability of different institutional arrangements among farmers, at both theoretical and practical levels.

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Artículo 5.

Collective action for multi-scale environmental management: Achieving landscape policy objectives through cooperation of local resource managers

[Acción colectiva para una gestión ambiental multi-escala: Alcanzando objetivos de políticas a nivel de paisaje a través de la cooperación de gestores de recursos locales]

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Abstract

The design of efficient public policies that aim to improve the provision of ecosystem services faces the problem that many ecosystem services are only apparent at spatial levels beyond the level at which they are managed. This makes it impossible to measure the contribution of individual resource managers to the provision of these services, as is the case in landscapes managed by private land-owners such as farmers. As a consequence, the magnitude of the public support associated with the implementation of a policy can not be specified down to the level of the individual manager/land owner. In this situation, institutional arrangements among resource managers are needed to determine how the public support defined at the higher level can be fairly distributed. This paper proposes a financial compensation arrangement among resource managers in a landscape, based on the Kaldor-Hicks criterion leading to a Pareto-optimal improvement, and explores the institutional requirements for the effective implementation of this arrangement. The proposed arrangement is illustrated with a case study in a woodland landscape in The Netherlands. The results show that private benefits among farms differed considerably due to biophysical, ecological and geographic differences among the farms. The financial compensation arrangement could contribute to improved equity among natural resource managers, which has been proposed as a key requirement for implementation of effective governance of environmental changes. The discussion addresses the institutional requirements of the proposed arrangement for governance structures that effectively deal with biophysical and socio-economic scale mismatches in sustainable use of natural resources.

Keywords: Landscape planning; collective action; agri-environmental policies; sustainability; agriculture.

Highlights: ▯ Community-based institutional arrangements may benefit natural resource management. ▯ A financial compensation arrangement based on collective action is proposed. ▯ Equitable distribution of compensations among individual land holders is targeted. ▯ The arrangement allows the implementation of optimal landscape configurations. ▯ Institutional requirements for the implementation of the arrangement are discussed.

1. Introduction

Most environmental problems related to sustainable use of natural resources by humans originate from scale mismatches within and among both the bio-physical and socio-economic dimensions of ecosystems (Cumming et al., 2006; Satake et al., 2008). Such scale mismatches occur because inherent and management-induced spatial variability of land and water bodies is apparent at local scales, whereas major positive and negative outcomes emerge at larger spatial scales of catchments and landscapes (e.g., Dalgaard et al., 2003; Ingram et al., 2008). Examples of emergent phenomena at larger scales are the load of non-point nutrient pollution from agriculture to streams and rivers, the ecological suitability of the habitat configuration in a landscape for survival of species, and the perception of landscape character as affected by the patchwork of agricultural and semi-natural landscape elements.

In the socio-economic dimension of sustainable resource use similar scale mismatches occur since the administrative entity of a landholding or farm is usually not aligned with the scale at which policy decisions are taken (e.g., Urwin and Jordan, 2008), or with the scale relevant for a range of public ecosystem services (Cumming et al., 2006). Here we define ecosystem services as the aspects of ecosystems utilized actively or passively to contribute to human well-being (Fisher et al., 2008). Therefore, coordination at a higher level by governmental orchestration or implementation of appropriate institutional structures at a lower level is needed. An important body of research is devoted to (neo-) institutional economic approaches to 1) determine governance structures optimal for providing public goods and services, and 2) to define market structures and institutional arrangements that are efficient in terms of transaction costs associated with policy implementation, such as search and information costs, negotiation costs, and control costs (reviewed by Renting et al., 2009). Governance is a highly contested concept in the social sciences with multiple meanings and implications: governance as the minimal state in contrast to ‘big government’ or strong state, ‘good governance’ as a policy condition, governance as part of the new public management, among others (Hezri and Dovers, 2006). Current debate on governance focuses on two key areas: efficiency and democracy (Kjaer, 2004). In public administration and public policy, efficiency is often associated with the institutions of service delivery (Hezri and Dovers, 2006). In this context institutions are defined as the organizations and rules of a society that facilitate coordination among people by helping them form expectations that each person can reasonably hold in dealing with others (Ruttan, 2003). In the area of economic relations they are crucial in establishing expectations about the rights to use resources and about the partitioning of the incoming streams resulting from economic activity (Ruttan, 2003). The second debate on democracy and governance is related to the growing importance of non-state actors in policy-making for the sake of accountability and legitimacy (Hezri and Dovers, 2006).

Conservation and restoration of large-scale natural resources can be effectively implemented when they are supported by collective action among individual private land-owners that act as natural resource managers at local level. Polman (2002) analysed different institutional arrangements and contractual forms for managing wildlife and landscape conservation in the Netherlands ranging from in-house production by the government to management by individually contracted farmers and intermediate 'hybrid' governance structures that aggregate the supply of public goods by groups of farmers. For spatially-bounded goods and services (landscape, biodiversity) institutional arrangements have the potential to create coherence and synergies in supply at territorial scale between individual farms, e.g. in the case of environmental cooperatives. Collective action among farmers showed to be decisive for the effectiveness of environmental schemes for wetland restoration, due to the physical interactions among landholdings and because of the cost saving and enhanced environmental benefit that can be achieved at a larger scale (Hodge and McNally, 2000). Marshall (2008) explored the 'nesting principle' proposed by Ostrom (1990) according to which appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises. This principle can foster robust common property governance of large-scale common-pool resources. Brondizio et al. (2009) discuss the challenges confronting environmental governance caused by the connectivity of resource-use systems and the growing functional interdependencies of ecological and social systems and highlight the role of institutions in facilitating cross-level governance as an important form of social capital.

Existing incentive programs to mobilize the ecosystem services potentially supplied by landscapes managed by private land-owners such as farmers coordination across holdings at the landscape level is typically neither required nor encouraged (Goldman et al., 2007). In The Netherlands for example, one of Europe's most intensive and productive farming areas, multifunctionality of agriculture is essentially operationalized in terms of protecting specific and localized ecological patrimony in zones (Daniel and Perraud, 2009). Cooperation among farmers is not targeted. A counter-movement is provided by the so-called environmental cooperatives built on the paradigm of community-based institutional arrangements for the management of natural resources. Their aim is to reach the objectives of the national policies with context specific measures acceptable to farmers and maintain the historical landscape which is the basis for a strong local identity (Renting and Van der Ploeg, 2001; Wiskerke et al., 2003).

Parra-López et al. (2008) proposed an integrated methodological framework for appraising the provision of multiple ecosystem services from landscapes consisting of a collection of spatially structured landscape elements managed by different private land-owners that act as natural resource managers. The provision of services was evaluated in terms of societal preferences, since understanding and satisfying social demands is the underlying principle to legitimize public support to natural resource management (NRM) by private land-owners, recently also confirmed in the European Landscape Convention (Sevenant and Antrop, 2010). Parra-López et al. (2009) developed a methodology to determine the most efficient public policy mechanisms to support changes towards a socially desirable configuration of NRM or penalize undesirable changes, by considering the aggregate net benefits for private land-owners as entrepreneurs and society as a whole. However, the way the support or penalisation would be distributed among the individual resource managers was not specified. Effects at the individual level need to be taken into account since individual resource managers are the driving agents of any change in management practices, with the private net benefit (e.g. gross margin) as the variable usually assumed to be a basic stimulus for action and change. The problem to accurately distribute the incentives (support or penalisation) to individual managers is that many environmental functions and services are only apparent at landscape level, which prevents measuring the contribution of individual resource managers to their provision. For instance, the ecological coherence that determines the accessible habitat area in a landscape for a certain animal species is determined by the configuration of landscape elements such as hedgerows at landscape level (Groot et al., 2010). It is a property of the landscape as a whole and cannot be specified for each individual land-owner/resource manager. Therefore, the individual contribution of resource managers to these ecosystem services can not be measured, and other criteria than the individual contribution need to be invoked to fairly distribute public stimulus to the level of the landholding and to achieve optimal landscapes.

The aim of this paper is to propose and discuss an institutional arrangement for collective action among land managers such as farmers aimed at achieving agri-environmental policy objectives, thus extending the methodological framework proposed by Parra-López et al. (2008; 2009). This will entail: (1) Defining a financial compensation arrangement among land managers in the manner of a formal theoretical procedure to mitigate individual financial damage ensuing from the implementation of an agri-environmental policy; (2) Discussing the institutional requirements and the actors and stakeholders involved to guarantee the implementation of the financial arrangement and the achievement of a desired landscape configuration. The institutional arrangement is based on the Kaldor-Hicks equity principle, which states that an outcome is more efficient if the individuals that are favoured by a change could 'in theory' compensate those that are disadvantaged by the change. This fits well with the governance principle of subsidiarity, which stipulates that matters should be organized at the level of the least centralized competent authority. A case study from a part of the Netherlands where collective action is rooted in environmental cooperatives is used to illustrate the financial compensation arrangement and to discuss requirements for its successful implementation as a means of supporting the achievement of landscape level policy objectives.

2. Landscape level policy evaluation and design

In this paper we use the term landscape for an area or region dominated by privately owned landholdings that use natural resources for the production of commodities and/or non-commodity outputs. The landholdings consist of a combination of (semi-) natural habitats and cultivated fields or forest parcels. The spatial arrangement of these landscape elements in the landscape along with their management is denoted the landscape configuration.

Parra-López et al. (2008; 2009) presented a methodological framework to evaluate the performance of private landholdings and design socially optimal agri-environmental polices at landscape level. Methodologically, the framework consists of two components, which are explained in the next sections: (1) Multi-criteria design and evaluation of natural resource management activities in landscapes; and (2) Selection of agri-environmental policies at landscape level.

2.1. Multi-criteria design and evaluation of natural resource management activities in landscapes

The provision of ecosystem services arising from market and non-market outputs can be linked directly to the land-use activities implemented by resource managers. In the study presented in this paper, we used Landscape IMAGES (Groot et al., 2007), which is a modelling and optimizing framework to assess the contribution of management at the level of fields and other landscape elements to economic and environmental performance at the landscape level. The assessment is guided by: 1) Societal preferences for ecosystem services, such as biodiversity conservation, landscape quality and environmental health, and 2) Private and public net benefits of a change of resource management compared to the current situation.

Societal preferences for ecosystem services are difficult to elicit directly from the public due their technical nature. Alternatively, they can be estimated indirectly through multi-criteria decision techniques by combining general demands of society for ecosystem performance and expert knowledge on the matter. General demands for ecosystem performance, such as to 'Promote the respect of environment' or 'Favour and improve life in the countryside' (Eurobarometer: EC, 2006), can be expressed by most citizens. A combination of Quality Function Deployment – QFD (Kogure and Akao, 1983) and Analytic Network Process – ANP (Saaty, 1996) was used to translate societal demands of Dutch citizens for ecosystem performance into the social benefits associated with non-market ecosystem services on the basis of assessments made by 10 experts on sustainable farming systems and with knowledge of the case study situation. The experts were individually interviewed following a structured questionnaire. A participatory process with local stakeholders in the case study (farmers, NGOs, etc.) was implemented both to specify some modelling variables (soil fertility, fertilizer application, etc.) and to inform them about the results obtained in the modelling process. This method is based on 'stated preferences' (based on questions in surveys), not on 'revealed preferences' (based on the real behaviour of people). Madureira et al. (2007) provide a discussion of their relative strengths and weaknesses. The availability of the Eurobarometer, based on stated preferences, made us decide to use them. Market benefits arising from a change in management practices were estimated for each economic agent: resource managers ($\Delta U_{M,MGR}$), consumers ($\Delta U_{M,CNS}$), and government ($\Delta U_{M,GOV}$). Market benefits were calculated in monetary terms within the neoclassical definition of surplus. For resource managers, the change in surplus is equal to the change in gross margin ($\Delta U_{M,MGR}=\Delta GM$). Change in gross margin for a farmer is the sum of revenues plus subsidies packages, according to existing agri-environmental policy support (AEPS), minus variable costs. For consumers, the surplus is null since in the case study price of the outputs from private landholdings (such as firewood, milk from cattle, or crop products) is assumed constant ($\Delta U_{M,CNS}=0$), and for government surplus increases if subsidies decrease ($\Delta U_{M,GOV}=-\Delta S$).

Resource managers deciding on new management practices and on the acceptability of new landscape configurations are limited by diverse institutional and technical restrictions. Technical restrictions have been taken account in modelling the set of management practices available and feasible alternative landscapes. Institutional restrictions were incorporated in the modelling process through the consideration of the rationale and the implicit sharing of property rights of agri-environmental schemes in The Netherlands. Managers' private net benefit (ΔU_{PRV}) is defined as the change in the market net benefits associated with a change of landscape configuration from the current situation:

$$\Delta U_{PRV} = \frac{\Delta U_{M,MGR}}{RU_M} = \frac{\Delta GM}{RU_M} \quad (1)$$

Where RU_M is a scaling factor describing the range of technically possible market net benefits associated with alternative landscape configurations, as calculated in Landscape IMAGES.

Public net benefit (ΔU_{PUB}) is defined as the sum of market net benefits for the other economic agents (government and consumers) and the non-market net benefits for all citizens:

$$\Delta U_{PUB} = \frac{\Delta U_{M,GOV} + \Delta U_{M,CNS}}{RU_M} + \frac{\sum_{i=1}^{n} \Delta U_{NM,i}}{RU_{NM}} = \frac{-\Delta S}{RU_M} + \frac{\sum_{i=1}^{n} \omega_{E_i} \cdot \ln\left[\frac{E_i(s)}{E_i(0)}\right]}{RU_{NM}} \quad (2)$$

Where $\Delta U_{NM,i}$ represents non-market benefits associated with the non-market ecosystem service E_i. $E_i(s)$ and $E_i(0)$ are the landscape performances in the non-market function E_i for a new situation (s) and for the current situation (0), respectively. Ecosystem services considered are landscape quality (LQ), referred to variation in number of plant species in pastures and to irregularity in the hedgerow pattern; nature value (NV), referred to species diversity in the grass swards and hedgerows (number of species per ha); and environmental health (EH), associated to low nitrogen loss from agriculture. Landscape performances in the non-market services were calculated from established empirical agro-ecological relations among management practices and the ecosystem services, which depend on the physical environment; ω_{Ei} is the priority or value that society gives to a marginal change in the non-market ecosystem service E_i; and RU_{NM} is the range of technically possible non-market net benefits associated with alternative landscape configurations as calculated in Landscape IMAGES.

The social net benefit at landscape level (ΔU_{SOC}) associated with a change in landscape configuration is the sum of the private benefits of resource managers, and the public net benefits. The aggregation of public and private, and market and non-market net benefits implies the compensation among sustainability dimensions which puts the approach under the weak sustainability paradigm (Martínez-Alier et al., 1998).

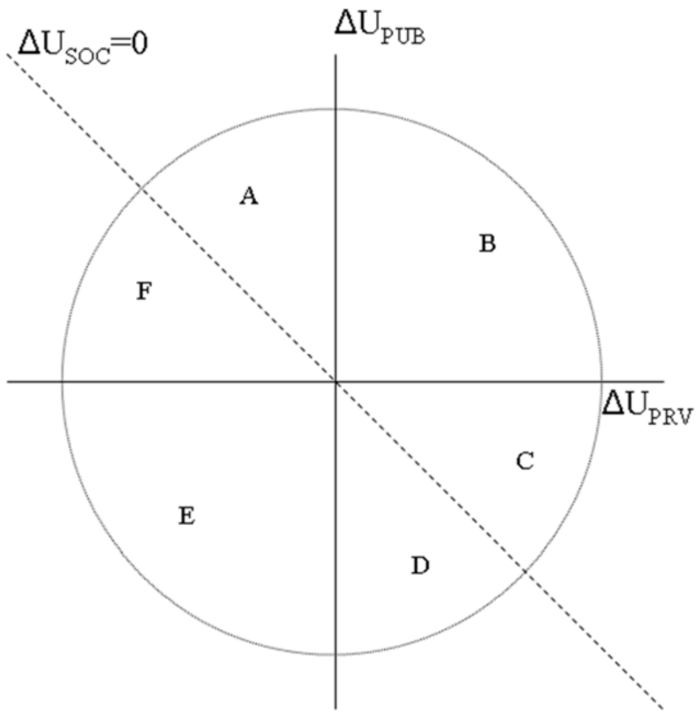
$$\Delta U_{SOC} = \Delta U_{PRV} + \Delta U_{PUB} \quad (3)$$

The Landscape IMAGES framework allowed to explore a set of potential landscape management configurations alternative to the current one in terms of the private and public net benefits. The exploration was carried out in three steps: (1) Determination of the extremes for individual performance criteria by single objective optimization; (2) Exploration of the trade-off frontiers between performance criteria by (2a) constrained single objective optimization, followed by (2b) multi-objective optimization; (3) Homogeneous spreading of solutions within the solution space.

2.2. Selection of agri-environmental policies at landscape level

Using the concept of a cost-effectiveness plane (Campbell et al., 2007), Pannell (2008) proposed a set of rules for policy selection on the basis of the private and public net benefits associated with land-use change. Starting from the current situation, different categories of policy mechanisms can be identified (Figure 1), which include 'Positive incentives' (region A) and 'Negative incentives' (region D). These incentives are an extra support (ES) at landscape level, additional to the existing AEPS incentives, positive in region A and a negative in D, to either compensate the resource managers willing to change to a desirable landscape configuration (region A), or to penalize change to undesirable landscapes (region D). It is defined as: ES = $-\Delta U_{M,MGR}$ = $-\Delta$GM. Recommended new support (NS) for new landscape configurations is NS = S + ES, where S is the level of support under the existing AEPS.

Figure 1. Policy mechanisms at landscape level on the basis of farmers' private and public net benefits in the regions A to F. (A) Positive incentives; (B) Extension; (C) No action (or flexible negative incentives); (D) Negative incentives; (E) No action (or extension or negative incentives); (F) Technology development (or no action). Note: The shape of the solution space is represented by a circle for illustration, but can take on any shape. The shape depends on the technical, ecological and economic options and restrictions. ΔU_{PRV}: Managers' private net benefit; ΔU_{PUB}: Public net benefit; ΔU_{SOC}: Social net benefit. Based on Parra-López et al. (2009).



Policy mechanisms do not only consist of positive and negative incentives to resource managers through subsidies and taxes, but also of non-financial actions that aim to spread socially valuable landscape configurations and the constituent management practices. For instance, extension (region B, Fig. 1) is a relatively cheap policy mechanism consisting of the transfer of scientific and technical knowledge to farmers. Extension would involve knowledge on 1) the availability of management practices and their profitability; 2) the positive ecological and financial consequences of landscape level practices; 3) the importance of collective action; and 4) the benefit of implementing the proposed financial compensation arrangement (see below) to foster equity among farmers.

Another policy mechanism is stimulating technology development to find improved landscape configuration options, such as through strategic R&D, participatory R&D with resource managers, and perhaps provision of infrastructure (Pannell, 2008). If farmers decide to change to a landscape configuration in region F, public policy should promote 'technology development', that is, the improvement of the production process to nullify the negative social net benefit of this landscape by either 1) further increase the (already) positive public net benefits of the new practices, through an improvement of the environmental performance of the production process; or 2) decreasing the negative private net benefits for farmers, through an improvement of the economic/financial performance of the production process.

3. Theoretical framework for financial compensation among resource managers

Policy mechanisms as described in the previous section are based on the aggregate net benefits of a change of landscape configuration to resource managers and society. The driving agents of any change in landscape configuration are individual resource managers with local control of only a small part of the landscape. Their private net benefit, here expressed as change in gross margin, is assumed to be the basic stimulus for action and change of their practices. Thus, a change in private net benefit of individual landholder is a necessary condition for the aspired change at the scale of the landscape. Similarly, if a landscape configuration representing negative public net benefit is economically attractive to some resource managers, they should be individually discouraged to change. In summary, policy mechanisms should be fine-tuned at the level of individual resource managers to account for individual market characteristics.

Some components of the public net benefits of a landscape as defined in this paper cannot be broken down to the local level since they refer to the landscape as a whole (e.g. ecological coherence) preventing to measure the contribution of individual farmers to these benefits. Landscape private benefit, however, can be disaggregated to the individual management units. Such disaggregation allows the definition of a financial compensation arrangement among resource managers and the refinement of policy mechanisms to meet locally specific conditions.

The relation between private net benefit at landscape level and private net benefit at the level of the management unit is:

$$\Delta GM = \frac{\sum_{\forall f} \Delta GM_f \cdot A_f + \sum_{\forall d} \Delta GM_d \cdot A_d}{A_T} \qquad (4)$$

Where *ΔGM* is the aggregated private net benefit for resource managers at landscape level, defined as the average change in gross margin for the farmers pertaining to the landscape and calculated by weighting individual changes in gross margins with the areas of the landholdings (€ ha^{-1}); $f \in (1, \ldots, F)$ is the set of favoured resource managers, benefiting from the change in landscape configuration by an increase in their individual gross margin; $d \in (1, \ldots, D)$ is the set of disadvantaged resource managers, who face a lower individual gross margin after implementation of the new landscape configuration; ΔGM_f and ΔGM_d are respectively the changes in gross margin of favoured ($\Delta GM_f \geq 0, \ \forall f$) and disadvantaged ($\Delta GM_d < 0, \ \forall d$) resource managers (€ ha^{-1}); A_f and A_d are areas of the landholdings of the favoured and disadvantaged resource managers (ha); and A_T is the total area of the landscape (ha), i.e. the sum of the areas of all landholdings.

If directions of change in private net benefit at landscape level and at the level of all individual resource managers coincide, policy has the same effect at landholding and landscape level. If directions of change at the different levels differ, we propose to implement the Kaldor-Hicks criterion of compensation: an outcome at landscape level is more efficient, and therefore more desirable, if the resource managers that are favoured, could 'in theory' compensate those that are disadvantaged by the change in landscape configuration. This theoretically leads to a Pareto-optimal improvement, that is, a change from one situation to another that makes at least one individual better off without making any other individual worse off. Compensations in gross margin among resource managers can be used to make the Kaldor-Hicks criterion operational. The key idea is to reduce the financial damage of disadvantaged resource managers as much as possible at the expense of those favoured and the extra support at landscape level when available, guaranteeing that favoured ones will not be financially damaged with respect to their current situation. We propose some basic rules to calculate these compensations (Table 1), which are developed in the next sections.

3.1. Increasing social net benefit ($\Delta U_{SOC}>0$)

The case of $\Delta U_{SOC}>0$ corresponds to regions A, B and C in Figure 1. A change from the current situation to alternatives in these regions entails a greater social benefit. No individual resource manager should experience economic losses; otherwise the change would be aborted. A distinction should be made between situations with increasing and decreasing private net benefit.

Table 1. Proposed financial compensation arrangement and its impact on resource managers' private benefits

a) Financial compensations among resource managers

Policy at landscape level			Compensations at landholding level (€ ha^{-1} yr^{-1})	
ΔU_{SOC}	ΔU_{PRV}	Region	Disadvantaged managers	Favoured managers
>0	<0	(A) Positive incentives	$C_d = -\Delta GM_d$	$C_f = -\Delta GM_f$
	>0	(B) Extension		$C_f = \Delta GM_f \cdot \frac{\sum_{\forall d} \Delta GM_d \cdot A_d}{\sum_{\forall f} \Delta GM_f \cdot A_f}$
		(C) No action		
<0	>0	(D) Negative incentives	$C_d = -\Delta GM_d$	$C_f = -\Delta GM_f$
	<0	(E) No action	$C_d = \Delta GM_d \cdot \frac{\sum_{\forall f} \Delta GM_f \cdot A_f}{\sum_{\forall d} \Delta GM_d \cdot A_d}$	
		(F) Technology development		

b) Resource managers' private net benefits after compensation

Policy at landscape level			Managers' private benefits after compensations (€ ha^{-1} yr^{-1})	
ΔU_{SOC}	ΔU_{PRV}	Region	Disadvantaged managers	Favoured managers
>0	<0	(A) Positive incentives	$\Delta GM'_d = 0$	$\Delta GM'_f = 0$
	>0	(B) Extension		$\Delta GM'_f = \Delta GM_f \cdot (1 + \frac{\sum_{\forall d} \Delta GM_d \cdot A_d}{\sum_{\forall f} \Delta GM_f \cdot A_f})$
		(C) No action		
<0	>0	(D) Negative incentives	$\Delta GM'_d = 0$	$\Delta GM'_f = 0$
	<0	(E) No action	$\Delta GM'_d = \Delta GM_d \cdot (1 + \frac{\sum_{\forall f} \Delta GM_f \cdot A_f}{\sum_{\forall d} \Delta GM_d \cdot A_d})$	
		(F) Technology development		

A) Increasing private net benefit (ΔU_{PRV}>0)

The case of ΔU_{SOC}>0 and ΔU_{PRV}>0 corresponds to regions B and C in Figure 1. Profits of favoured resource managers are greater than losses of disadvantaged managers, and therefore favoured may compensate disadvantaged managers. Each disadvantaged manager should be compensated exactly for the loss of private net benefit. In this way reticence of disadvantaged managers to adopt the new management practices would be avoided. Favoured managers should contribute to the compensation of the disadvantaged managers in proportion to their share in aggregate benefits (Table 1a):

$$C_d = -\Delta GM_d \quad (5)$$

$$C_f = \Delta GM_f \cdot \frac{\sum_{\forall d} \Delta GM_d \cdot A_d}{\sum_{\forall f} \Delta GM_f \cdot A_f} \quad (6)$$

Where C_d and C_f are the compensation for disadvantaged manager d (€ ha^{-1}) and for favoured manager f (€ ha^{-1}), respectively. These expressions are valid for all f ϵ (1, …, F) and all d ϵ (1, …, D). The private net benefits after compensation (ΔGM') are shown in Table 1b.

B) Decreasing private net benefit (ΔUPRV<0)

The situation $\Delta U_{SOC}>0$ and $\Delta U_{PRV}<0$ corresponds to region A 'Positive incentives' in Figure 1. Aggregate profits of favoured resource managers are smaller than aggregate losses of disadvantaged managers, and therefore the profits of the favoured managers are not enough to compensate the disadvantaged. The difference between the profits of favoured and the losses of disadvantaged managers is exactly the extra support (ES, € ha^{-1}) that society should provide as shown in the previous section.

As in the previous case, each disadvantaged farmer should be compensated exactly for the loss of private net benefit (Equation 5), thus repairing the net benefit to zero after compensation. Favoured managers should contribute to the compensation of the disadvantaged managers in proportion to their share in aggregate benefits after considering the positive extra support available (Table 1a):

$$C_f = \Delta GM_f \cdot \frac{\sum_{\forall d} \Delta GM_d \cdot A_d + ES \cdot A_T}{\sum_{\forall f} \Delta GM_f \cdot A_f} \qquad (7)$$

Taking into account the definition of the extra support (ES = –ΔGM) and Equation 4, Equation 7 can be written as:

$$C_f = -\Delta GM_f \qquad (8)$$

This entails that favoured managers contribute with all their private benefits. The individual private net benefits of all farmers after compensation would be zero (see Table 1b).

3.2. Decreasing social net benefit (ΔU_{SOC}<0)

The case of ΔU_{SOC}<0 corresponds to regions D, E and F in Figure 1. Changes from the current situation to these landscape configurations entail a lower social benefit. Therefore, public intervention should not support these changes. However, individual landholders are free to change. As for the case with ΔU_{SOC}>0 (Section 3.1) we propose rules to reduce the financial damage of disadvantaged resource managers as much as possible at the expense of favoured managers, considering possible negative extra support when applicable to make the change more efficient in terms of the Kaldor-Hicks criterion. Again, two cases can be distinguished.

A) Decreasing private net benefit (ΔUPRV<0)

The situation ΔU_{SOC}<0 and ΔU_{PRV}<0 corresponds to regions E and F in Figure 1. Losses of disadvantaged managers surpass gains of favoured managers, and therefore these gains are not enough to compensate losses. Favoured managers should contribute to the partial compensation of the disadvantaged with their total benefit. Disadvantaged managers should be compensated in proportion to their share in aggregate loss of private net benefit (Table 1a):

$$C_f = -\Delta GM_f \tag{9}$$

$$C_d = \Delta GM_d \cdot \frac{\sum_{\forall f} \Delta GM_f \cdot A_f}{\sum_{\forall d} \Delta GM_d \cdot A_d} \tag{10}$$

Private net benefits after compensation are shown in Table 1b.

B) Increasing private net benefit (ΔUPRV>0)

Landscape configurations characterized by $\Delta U_{SOC}<0$ and $\Delta U_{PRV}>0$ are situated in region D 'Negative incentives' in Figure 1. Gains of favoured managers are greater than losses of disadvantaged managers, and therefore the favoured managers may completely compensate the disadvantaged managers. The remainder of gains is exactly the extra support (ES) that society requires from the managers to avoid aggregate private benefits at the expense of society, as shown in the previous section.

As in the previous case, each favoured manager should contribute with the total benefit to the compensation of disadvantaged (Equation 9). Disadvantaged managers should be compensated in proportion to their share in aggregate loss at the expenses of the profits of favoured after considering the negative extra support required:

$$C_d = \Delta GM_d \cdot \frac{\sum_{\forall f} \Delta GM_f \cdot A_f + ES \cdot A_T}{\sum_{\forall d} \Delta GM_d \cdot A_d} \tag{11}$$

Equation (11) can be rewritten considering the definition of the extra support and Equation (4), as:

$$C_d = -\Delta GM_d \quad (12)$$

This entails that disadvantaged managers will be completely compensated for their losses. The overall private net benefits of all farmers after compensation would be zero (see Table 1b).

4. Case study: Northern Friesian Woodlands

The compensation framework for collective action is illustrated with an example from the Northern Friesian Woodlands, The Netherlands. This is a region characterized by area high density of linear landscape elements such as hedgerows, and intensive dairy farming as the main land-use activity. The fields with an average size of 2 ha are mainly under permanent pastures that are rotationally grazed and mown. Grazing systems range from day and night grazing to restricted- and zero-grazing. A limited proportion of up to 5% of the area on some farms is used for forage maize production. All these characteristics configure a traditional landscape widely appreciated and deeply rooted among local people in particular, and the Dutch in general. The high potential of the region to provide non-productive amenities has recently been argued to sustain farming in the area (Berentsen et al., 2007).

In this region the first environmental cooperatives appeared in the 1990s. Environmental cooperatives VEL (Vereniging Eastermar's Lânsdouwe) and VANLA (Vereniging Agrarisch beheer Natuur en Landschap in Achtkarspelen) were founded to counterbalance the predominantly generic and means-oriented policy interventions. The main objective of the policies was to reduce emissions of ammonia and nitrate to the environment. The aim of the cooperatives was to achieve the goals of the national policies but through context-specific measures acceptable for farmers, and to maintain the historical landscapes of the region through even more strict measures than prescribed by national and European policies. The basic unit of action of environmental cooperatives is the landscape, collectively managed through farm level specific activities. In this paper, we analyze an area of 232 ha in the region.

The analysed case study is based on: 1) Three landholdings (farms) with ca. 20 fields per farm and hedgerows on a number of field borders; 2) Two types of land-use activities, the first type pasture and its fertilizer (amount and timing) and harvesting regimes (mowing and grazing), and the second type field borders, which may or may not contain a hedgerow; 3) Two market services (gross margin and subsidies) and three non-market services (landscape quality – LQ, nature value – NV, and environmental health – EH).

5. Results

In section 5.1, we summarise the key findings of Parra-López et al. (2009), needed to present in section 5.2 the proposed financial compensation arrangement for collective action.

5.1. Agricultural policies at landscape level

A total of 1261 alternative landscape management configurations were generated according to the methodology described in Section 2.1. This allowed the joint estimation of the private net benefit for resource managers (ΔU_{PRV}) and public net benefit (ΔU_{PUB}) of potential changes in landscape configuration, as well as the social net benefit associated with these changes (ΔU_{SOC}).

Subsequently, as described in Section 2.2 specific landscape configurations were selected among the 1261 alternatives based on their ΔU_{PRV}, ΔU_{PUB}, and ΔU_{SOC}, and the most efficient policy mechanisms to achieve or avoid these landscape configurations were determined. Four prototype agro-landscapes were selected to illustrate different selection criteria, the associated public and private benefits and the efficient policy mechanism (Table 2). Other selections might be made, e.g. based on the availability of public resources for support, 'ideological' preferences of policy makers, or lexicographic preferences over available configurations. Here we describe the results for the four landscape configurations.

Table 2. Characterisation of current and alternative landscape configurations in the case study

Variable	Current situation	Social optimum	No action	Maximum public net benefit	Maximum farmers net benefit
Gross margin [GM] (€ ha^{-1} yr^{-1})	2917.43	2947.91	3057.33	2823.42	3714.13
Current support [S] (€ ha^{-1} yr^{-1})	199.59	70.68	72.80	85.17	1136.68
Landscape quality [LQ] (-)	88.54	122.44	39.13	114.42	16.60
Nature value [NV] (-)	41.28	37.27	13.20	58.65	42.56
Environmental health [EH] (kg^{-1} N ha yr)	0.0076	0.0071	0.0066	0.0121	0.1089
$\Delta U_{M,MGR}$ [ΔGM] (€ ha^{-1} yr^{-1})	0.00	30.48	139.90	-94.01	796.70
$\Delta U_{M,GOV}$ [-ΔS] (€ ha^{-1} yr^{-1})	0.00	128.91	126.78	114.42	-937.09
$\Delta U_{NM,LQ}$ (-)	0.0000	0.1047	-0.2635	0.0828	-0.5403
$\Delta U_{NM,NV}$ (-)	0.0000	-0.0295	-0.3300	0.1016	0.0088
$\Delta U_{NM,EH}$ (-)	0.0000	-0.0271	-0.0579	0.1809	1.0320
ΔU_{PRV} (-)	0.0000	0.0389	0.1783	-0.1198	1.0155
ΔU_{PUB} (-)	0.0000	0.1773	-0.0147	0.2447	-1.0590
ΔU_{SOC} (-)	0.0000	0.2161	0.1636	0.1249	-0.0435
Policy mechanism	-	Extension	No action (or flexible negative incentives)	Positive incentives	Negative incentives
Extra support [ES] (€ ha^{-1} yr^{-1})	0.00	0.00	0.00	94.01	-796.70
New support [NS] (€ ha^{-1} yr^{-1})	199.59	70.68	72.80	179.18	339.98

Note: For explanation of the variables see text; (-) = dimensionless
Source: Parra-López et al. (2009)

The 'Social optimum' alternative maximises social net benefit. This landscape configuration entails the largest increase in social benefit compared to the current situation (ΔU_{SOC}=0.2161; Table 2) and provides both positive public benefits (ΔU_{PUB}=0.1773) and positive managers' private benefits (ΔU_{PRV}=0.0389). The social optimum is associated with an increase in landscape quality, due to a higher variation in number of plant species in pastures and/or more irregularity of the hedgerow pattern, but a slight decrease in nature value and environmental health of the landscape, due to lower species diversity in the grass swards and hedgerows and higher nitrogen loss from agriculture. Gross margins of managers would increase around 1% (from 2917.43 to 2947.91 € ha^{-1} yr^{-1}) even with 65% lower subsidies from agri-environmental schemes (reduced from 199.59 to 70.68 € ha^{-1} yr^{-1}). The efficient policy mechanism to favour the change towards the 'social optimum' agro-landscape is 'extension' (region B in Figure 1), because the private net benefits of adoption are positive for the set of resource managers as a whole.

The 'No action' landscape configuration would maximise social net benefits on absence of public policy intervention. The landscape configuration is characterized by a positive change in social benefit (ΔU_{SOC}=0.1636) and positive change in farmers' private benefits (ΔU_{PRV}=0.1783). Resource managers could be attracted by this benefit and freely adopt these practices, but the negative public net benefits (ΔU_{PUB}=-0.0147) disallow public intervention. Negative effects are due to poor environmental performance, with decreases in landscape quality nature value and environmental health (Table 2). Since it is known that private net benefits are sufficient to outweigh public net costs, flexible negative incentives do not apply (Pannell, 2008).

The 'Maximum public net benefit' landscape configuration would entail the highest public benefit (ΔU_{PUB}=0.2447), associated with improvements in each environmental indicator, but a decrease in private benefits (ΔU_{PRV}=–0.1198). This decrease is smaller than the increase in public benefit, and therefore society as a whole would gain. The most efficient policy mechanism to achieve this alternative is 'positive incentives' to mitigate the losses of farmers with an extra support (ES) of 94.01 € ha^{-1} yr^{-1} to be added to the support of 85.17 € ha^{-1} yr^{-1} that these practice have under the current agri-environmental support.

With the 'Maximum farmers net benefit' landscape configuration resource managers would maximise their private benefit (ΔU_{PRV}= 1.0155). The gain in private benefit would be surpassed by a public loss (ΔU_{PUB}=-1.0590), resulting in a decrease of social net benefit. Negative incentives should be used as policy mechanism to dissuade farmers to adopt these practices. They should be equal in absolute terms to the hypothetical increase of gross margin for the set of farmers (ES=–796.70 € ha^{-1}

yr^{-1}) to nullify their benefit and avoid change.

5.2. Compensation at landholding level

For each landscape configuration, Table 3 describes the effects of the application of the proposed financial compensation arrangement at the level of the three landholdings in the case study. The effects are described in terms of 1) the changes in the private net benefit per farm if no financial compensation arrangement is implemented (ΔGM_i); 2) the proposed compensation for each farm (C_i); and 3) the resulting changes in the private farmers' net benefit under the financial compensation arrangement ($\Delta GM'_i$). The results show that without compensation farm 1 always benefits from changes in landscape configuration, and would achieve higher net benefits than farms 2 and 3, which incur negative net benefits in some landscape alternatives.

Table 3. Effects of the financial compensation arrangement at the landholding level illustrated for four alternative landscape configurations

Variable	Farm*	Social optimum	No action	Maximum public net benefit	Maximum farmers net benefit
Δ Gross margin before compensation [ΔGM_i] (€ ha^{-1} yr^{-1})	1	156.93	248.92	30.64	918.06
	2	-6.21	122.84	-135.56	775.82
	3	-74.56	28.73	-189.96	675.62
Compensation [C_i] (€ ha^{-1} yr^{-1})	1	-67.15	0.00	-30.64	-918.06
	2	6.21	0.00	135.56	-775.82
	3	74.56	0.00	189.96	-675.62
Δ Gross margin after compensation [$\Delta GM'_i$] (€ ha^{-1} yr^{-1})	1	89.78	248.92	0.00	0.00
	2	0.00	122.84	0.00	0.00
	3	0.00	28.73	0.00	0.00

Note: For explanation of the variables see text

* *Area of the landholdings: 43.7, 49.8 and 35.2 ha; in total 128.7 ha*

The arrangement suggested for the 'social optimum' is compensation of the disadvantaged managers (farms 2 and 3) by the favoured farmer according to the equations in Table 1 for the policy 'B Extension'. Manager 2 should receive 6.21 € ha^{-1} yr^{-1} and manager 3 74.56 € ha^{-1} yr^{-1}. Manager 1 should renounce to 67.15 € ha^{-1} yr^{-1} (Table 3). The private net benefit of managers 2 and 3 after compensation would be zero, and that of manager 1 will be reduced from 156.93 to 89.78 € ha^{-1} yr^{-1}.

The 'no action' alternative is characterized by gains in private net benefit for each of the managers (ΔGM_i in Table 3). Since there are no disadvantaged managers no compensation is required.

The landscape configuration of the 'maximum public net benefit' alternative is located in region 'A Positive incentives' of Figure 1. Gains of manager 1 are smaller than losses of manager 2 and 3 (ΔGM_i in Table 3). As a result, losses can not be compensated solely from the gains of manager 1 but need to be complemented by extra support (ES) from society. The disadvantaged managers are compensated, while the favoured manager gives up the gain of 30.64 € ha^{-1} yr^{-1}. Net benefit after compensation equals zero for each manager.

The landscape configuration of the 'maximum farmers net benefit' alternative is located in region 'D Negative incentives' (Figure 1). This landscape configuration would entail negative social net benefits, and public intervention should discourage the change by nullifying the net private benefits of the three (favoured) managers through a negative extra support ES (-796.70 € ha^{-1} yr^{-1}, Table 2).

6. Discussion

This study aims to contribute to the definition of institutional arrangements that are optimal for jointly providing market products and public goods and services. Specifically a financial compensation arrangement for collective action based on the Kaldor-Hicks criterion was proposed to overcome socio-economic scale mismatches between resource management decisions at the level of individual landholdings and policy ambitions which become manifest at the landscape level. The proposed financial compensation arrangement further extends the methodological framework of Parra-López et al. (2008; 2009) by facilitating the implementation at farm level of socially optimal agri-environmental policies targeted at landscape level. In particular, the financial compensation arrangement would allow increasing the equity of individual resource managers by transfer of gross margin from farmers that benefit from landscape configuration changes to those that would have to sacrifice gross margin under the new conditions. Improved equity in natural resource management areas has been proposed as one of the key attributes of sustainable development (Okey, 1996), and could reduce transaction costs for the implementation of policies (Vatn, 2002).

The assessment model used in the proposed framework – the Landscape IMAGES model (Groot et al., 2007) – is a static model suitable for assessment in the short term, assuming constant prices of inputs and outputs. In the case of a time horizon long enough to allow changes in prices it would be necessary to build a series of static models for different moments in time, which would yield separate solution spaces. However, the static approach is enough as to define landscape policies and financial compensation arrangements among farmers in the short time, e.g. for a period of 5 years (or less) that is the common period in current agri-environmental contracts, by using estimated average prices of inputs and outputs for this period in the modelling process.

An assumption in the proposed financial arrangement is that private net benefit operates as the driving force for farmers' decision to adopt new management practices, as in the basic version of Pannell's proposal (Pannell, 2008). This does not imply that each farmer acts as a perfect 'homo economicus' trying to maximize his/her private benefits. On the contrary, some degree of solidarity with others and with society in general is required to achieve more sustainable landscape configurations. In rural social sciences it is recognised that landholders' perceptions of their self-interest often run broader than financial considerations. Refinements of the framework that include learning and transaction costs remain for future research.

The local cooperation assumption of the financial compensation arrangement is anchored in the concept of subsidiarity in the design of NRM governance structures. Collective action among resource managers is a key element to overcome socio-economic scale mismatches and is an important institutional requirement for the implementation of the financial compensation arrangement. Why and when social agents cooperate has been topic of both empirical and theoretical research. Laboratory experiments and case study analysis (Ostrom, 1990; Ostrom et al., 1994) have demonstrated that people have the capacity to organize themselves and achieve much better outcomes than is predicted by conventional economic theory (Janssen, 2004). A critical issue for stimulating and maintaining cooperative behaviour is communication and the ability of the participants to develop and apply a monitoring and sanctioning system (Ostrom et al., 1994). For a population of agents to voluntarily restrict their own behaviour in order to avoid the collapse of a resource in the long term, mutual trust relationships are a requirement, since it is essential that each agent is confident that the others will also reduce the use of the resource (Janssen and Ostrom, 2002). In the same direction Marshall (2004) indicated that farmers' preparedness to cooperate is more related to their perceptions of community benefits and trust that others will also cooperate, than it is to private benefits such as business security, usually focussed upon by governments in attempting to motivate cooperation to implement programs of natural resources governance. Fuller (2009) examined the consensus building processes that seek an agreement among stakeholders who believe they have 'apparently irreconcilable differences', concluding that it is crucial to create an inter-language (words and concepts), as well as the habits, rules, and procedures to use them effectively. Decentralized governmental, non-governmental and farmers' organizations should take responsibility for implementation, administration and monitoring of landscape plans (Penker, 2009; Pretty et al., 2001). In addition, Marshall (2009) highlighted the positive relationship between multiple decision-making centres with considerable autonomy for community-based NRM and farmers' willingness to cooperate voluntarily in adopting conservation practices in an Australia-wide governance experiment.

In the case study area, well-established so-called environmental cooperatives (Renting and Van der Ploeg, 2001) constitute a form basis for effective institutional arrangements as proposed here. Recently, several municipal environmental cooperatives in this area have merged to create a regional cooperative, which aims to establish contracts with the Dutch government wherein the participating farmers are rewarded or punished as a group for succeeding or failing to reach environmental objectives (Anonymous, 2005). Initially, these objectives focused on reduction of nutrient losses at regional scale, but gradually more attention is being paid to development of ecosystem services related to biodiversity and landscape. The differential effect of a change in landscape configuration for the constituent farms in our illustration was due to differences in the physical, ecological and geographic characteristics among the farms. Gradients in soil fertility and in the arrangement of natural elements in the current landscape caused farms 2 and 3 to be always worse off than farm 1. Such geographical heterogeneity is a pervasive characteristic of landscapes and highly recognizable by landholders but is thus far rarely taken into account in developing governance schemes (Bateman, 2009; Renting and Van der Ploeg, 2001). The compensation scheme proposed in this paper may be of interest in such kind of situations. Our results also illustrated that financial compensation is not always needed, for instance for the 'no action' landscape configuration where there were no disadvantaged managers. Community-based approaches to environmental issues have not been widely used in the EU but are widespread in Australia, New Zealand and Canada. Keenleyside et al. (2009) noted that community-led projects, in which farmers usually play a large role, can help to build social capital, promote cooperative working and deliver environmental benefits at a scale broader than that of an individual farm.

The analysis showed that policies designed at landscape level may bring about landscape configurations that are superior in terms of public and aggregate private benefits, but will be unacceptable for some landholders. The opposite case has been also detected: private benefits for a few landholders could lead to undesirable results for the other resource managers and for society. In such socially sub-optimal cases, collective action among resource managers is decisive and the implementation of a financial compensation arrangement would be required. The institutionalization of the financial compensation arrangement could be implemented through either informal institutions, such as verbal agreement among farmers, or formal ones, such as through contractual forms among farmers. Additionally, the wider diffusion of the proposed financial arrangement and the collaboration among farmers should be promoted and supported from higher policy-spheres in the form of formal institutions such as the agri-environmental schemes which are elaborated and applied at national level. The research highlights the need of community-based institutional arrangements for the management of natural resources and their consideration in existing agri-environmental schemes since cooperation among resource managers is in general not targeted in these programs.

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DISCUSIÓN GENERAL

Discusión general

La Unión Europea viene promoviendo en las últimas décadas, y continúa profundizando en esa dirección en la nueva PAC 2014-2020, una agricultura multifuncional y sostenible económica, ambiental y socialmente, que compatibilice la producción de alimentos y materias primas (bienes de mercado) con el respeto del medio ambiente y el bienestar social (bienes y servicios de no-mercado o externalidades). Ello es debido a que cuestiones como la conservación de la biodiversidad, la menor contaminación de las aguas y el suelo, el control de la erosión del suelo, la mejora de la calidad del paisaje y la fijación de la población rural son funciones de la agricultura cada vez más demandas por la sociedad. La evaluación de la multifuncionalidad de la agricultura y el diseño de políticas agrarias que propicien su mayor sostenibilidad global es, por tanto, un tema de máxima prioridad tanto en la agenda política como en el ámbito académico. Los sistemas agrarios olivareros de Andalucía y ganaderos lecheros de los Países Bajos, analizados en la presente Tesis Doctoral, son de una gran relevancia dada su importancia a nivel económico, social y ambiental en sus respectivas regiones. Por tanto, la mejora de la sostenibilidad de estas actividades agrarias en dichas regiones presenta un elevado interés y una incidencia potencialmente alta en el bienestar de un gran número de actores económicos y de la sociedad en general. En este contexto, la presente Tesis Doctoral trata de contribuir a la teoría y práctica de la evaluación y mejora de la sostenibilidad agraria desarrollando un marco metodológico integrado con el fin de evaluar y definir prácticas agrarias más sostenibles económica, ambiental y socialmente, y diseñar políticas agrarias eficientes en términos de costes que favorezcan la adopción de técnicas óptimas desde el punto de vista de su sostenibilidad, aplicándolo a los dos sistemas agrarios indicados: olivar de Andalucía y ganadería lechera de los Países Bajos. A continuación se discuten las principales cuestiones metodológicas planteadas así como los principales resultados obtenidos durante la realización de la Tesis, que se corresponden con los grandes objetivos de la misma.

1. Marco metodológico integrado propuesto

Dada la importancia de la promoción de la multifuncionalidad y la sostenibilidad en la práctica, se requiere un marco conceptual sólido que permita distinguir las acciones y políticas sostenibles de las que no lo son (Vanderheiden, 2008). Uno de los grandes retos que se plantean es que se está tratando con sistemas muy complejos y situaciones en las que la incertidumbre es muy elevada. En efecto, nos encontramos con sistemas agro-ecológicos vivos con múltiples funciones y complejas interacciones entre las prácticas agrarias implementadas, las condiciones ambientales, ecológicas y climáticas del medio en el que se desarrollan los cultivos, y el entorno económico e institucional que condiciona la actividad agraria (Zander et al., 2008). Además, se presentan múltiples conflictos entre valores e intereses que compiten y diferentes grupos y comunidades que los representan (Martinez-Alier et al., 1998). Así, es necesario el examen conjunto de las funciones económicas, ambientales y sociales de la agricultura, teniendo en cuenta los beneficios y los costes privados y públicos para el sector productivo, los consumidores, la administración pública y la sociedad en general. La evaluación de la multifuncionalidad y la sostenibilidad presenta una serie de características como son la incertidumbre, la irreversibilidad y la consideración de las generaciones futuras, que hacen su ejecución práctica realmente difícil (Moreno Jiménez, 1997). Estas consideraciones impiden la construcción de modelos muy simplificados de la realidad si no se quiere perder información importante sobre la misma. Dado que existe un trade-off entre la sencillez y la precisión (Janssen y van Ittersum, 2007), se debe buscar la simplificación de los modelos hasta un nivel de precisión adecuado para la resolución de problemas y apoyo a las decisiones (Zander et al., 2008).

El carácter de 'bienes públicos' de muchas de las funciones no comerciales de la agricultura hace que con frecuencia la intervención pública sea necesaria para alcanzar los intereses sociales (Zander et al., 2008). Sin embargo, la información es escasa en el debate público sobre lo que la sociedad realmente exige, en particular con respecto a los objetivos sociales de la multifuncionalidad (Rossing et al., 2007), y, por extensión, sobre cuál debe ser el suministro óptimo de bienes públicos por la agricultura (Hall et al., 2004). La satisfacción de la demanda social para los bienes de no-mercado y el nivel de sostenibilidad de una actividad agraria determina hasta qué punto dicha actividad agraria debe ser fomentada por la sociedad (Zander et al., 2008).

Las demandas de la sociedad son evaluadas por lo general usando técnicas de preferencia expresada mediante valoración monetaria, como la Valoración Contingente (Contingent Valuation), los Gastos de Viaje (Travel Costs) y Ordenación/Clasificación Contingente (Contingent Ranking) (Lima e Santos, 2001), y más recientemente Experimentos de Elección (Choice Experiments) y técnicas relacionadas derivadas de Análisis Conjunto (Conjoint Analysis) (Zander et al., 2008). Estas metodologías están en general basadas en la simulación de un mercado hipotético a través de un cuestionario, registrando la disposición a pagar de las personas para que un determinado cambio se produzca o no. Dada la escasa aceptación pública de las valoraciones monetarias, el análisis de los trade-offs entre las funciones de mercado y no-mercado (comportamiento económico/financiero frente ambiental y social) puede ser útil para la toma de decisiones de política pública (Stoorvogel et al., 2004). Son necesarias combinaciones metodológicas alternativas e innovadoras para la incorporación de las preferencias sociales en el diseño de políticas (Zander et al., 2008).

En este contexto, diferentes autores opinan que la resolución de problemas de evaluación complejos como es la evaluación de la multifuncionalidad y sostenibilidad agraria podría plantearse fructíferamente alejándose, por una parte, de la ortodoxia de la Economía Neoclásica y aproximándose, por otra parte, a la Teoría de la Decisión Multicriterio y a la Economía Ecológica (Hernández y Cardells, 1999). Desde la Economía Ecológica, campo transdisciplinar de investigación, se ha sugerido que un enfoque integrado, no necesariamente monetario, que combine la valoración económica, la modelización integrada, el análisis de las partes interesadas y la evaluación multicriterio puede proporcionar información complementaria y nuevas claves en el diseño de políticas orientadas a la sostenibilidad y el bienestar social (Turner et al., 2000). Un enfoque integrado requiere que el análisis sea: a) holístico, incorporando de manera conjunta una amplia gama de prácticas y técnicas agrarias y funciones de la agricultura, algunas de ellas poco representadas en la literatura, en especial las relacionadas con temas sociales, bióticos y paisajísticos (Rossing et al., 2007), tales como las funciones analizadas en la Tesis relativas al desarrollo rural y el empleo, la identidad cultural y el paisaje y la biodiversidad; b) sistémico, considerando la producción agrícola como un sistema compuesto por diversos elementos, como técnicas de cultivo y funciones, interrelacionadas a través de patrones mecanicistas en forma de relaciones de red definidos por matrices ANP en la Tesis, lo que permite predicciones y simulaciones (Janssen y van Ittersum, 2007); c) integrador, incorporando información de distinta naturaleza y nivel de complejidad, desde datos cuantitativos contrastados de fuentes secundarias hasta información cualitativa, subjetiva e intangible basada en el conocimiento de expertos y recopilada ad-hoc; y d) transdisciplinario, permitiendo la comunicación entre científicos de diferentes disciplinas, como la agronomía, la ecología y la economía, por medio de un lenguaje común de resolución de problemas sobre la base de las matemáticas; y facilitando la comunicación con otras partes interesadas, tales como gerentes, administradores y el público en general, a través de un lenguaje fácil de usar basado en la síntesis de la información.

Una parte importante de la Tesis se ha dedicado al desarrollo desde esta perspectiva integrada de un marco metodológico para la evaluación de la multifuncionalidad y sostenibilidad de los sistemas agrarios y el diseño de políticas agrarias eficientes. Para ello se han combinado diferentes metodologías y desarrollos teóricos como la teoría de la utilidad neoclásica, la modelización agro-económica mediante técnicas multicriterio y de optimización multiobjetivo, y el análisis de las demandas sociales a la agricultura mediante técnicas multicriterio. Se han desarrollado una serie de modelos: 1) un modelo agro-ecológico basado en la metodología multicriterio ANP que relaciona prácticas agrarias con funciones en el caso del olivar (artículo 1); 2) un modelo agro-ecológico basado en el marco de optimización multiobjetivo LANDSCAPE Images para relacionar prácticas agrarias con funciones en el caso de la ganadería lechera (artículo 3); 3) un modelo de demandas sociales basado en la metodología multicriterio ANP para relacionar las funciones de no-mercado de los sistemas agrarios con las demandas sociales hacia la agricultura y determinar los beneficios públicos netos en el caso del olivar (artículo 2); 4) un modelo de demandas sociales basado en la metodología multicriterio ANP/QFD para relacionar las funciones de no-mercado de los sistemas agrarios con las demandas sociales por la agricultura y determinar los beneficios públicos netos en el caso de la ganadería lechera (artículos 3 y 4); 5) un modelo de diseño de políticas eficientes en función de los beneficios privados y públicos netos basado en el marco BPPN, tanto para el olivar (artículo 2) como para la ganadería lechera (artículo 4); y 6) un mecanismo institucional de compensación financiera, para el caso de los Países Bajos, basado en el criterio de Kaldor-Hicks y la mejora de Pareto, para la distribución a nivel agricultor del apoyo público definido a nivel de paisaje y facilitar la adopción conjunta de los sistemas agrarios más sostenibles (artículo 5).

En el proceso de definición de los modelos agro-ecológicos, en los dos casos de estudio, se siguió un enfoque de ingeniería agro-ecológica mecanicista (Ittersum y Rabbinge, 1997; Parra-López et al., 2008b). Esto supone que el comportamiento/outputs en las múltiples funciones - económica, social y ambiental - de un sistema agrario a nivel de explotación en un determinado contexto agronómico, socioeconómico y ambiental viene determinado totalmente por las técnicas agrarias/inputs utilizados. Esta perspectiva es diferente de los enfoques econométricos empíricos clásicos en los que las combinaciones de inputs-outputs y las funciones de producción se basan en la experimentación práctica, las estadísticas o las extrapolaciones para ciertas condiciones muy restrictivas (Ittersum y Rabbinge, 1997), por lo que es difícil extrapolar a opciones tecnológicas diferentes o nuevas restricciones y políticas (Janssen y van Ittersum, 2007). Por el contrario, ANP y LANDSCAPE Images permiten un enfoque mecanicista en el que los modelos se basan en la teoría y el conocimiento existente de los procesos agrícolas, siendo posible hacer predicciones y simulaciones a largo plazo fuera de un estrecho rango de datos observados (Janssen y van Ittersum, 2007).

ANP (y su modelo más básico, AHP) (Saaty, 1980; Saaty, 2001) es una herramienta analítica que permite la resolución de problemas de toma de decisión complejos, con múltiples criterios y agentes implicados, en escenarios de gran incertidumbre (falta de información) y riesgo (lo que está en juego). Esta metodología permite comparar explícitamente factores tangibles e intangibles, incorporar información objetiva y subjetiva y utilizar fuentes cuantitativas y cualitativas (Saaty, 2001). ANP hace más transparente y objetivo el proceso de toma de decisiones al ser necesario explicitar las preferencias de los diferentes agentes implicados en la toma de decisiones, lo que facilita la comunicación entre las partes interesadas, y ahorra costes y tiempo al permitir la utilización de una amplia gama de fuentes de información (Parra-López et al., 2008a). Además, permite un continuo proceso de aprendizaje de los agentes decisores, siendo posible y recomendable retroalimentar con la información resultante las fases iniciales del proceso de toma de decisiones (Forman y Selly, 2001). ANP es, por tanto, un proceso para la toma de decisiones en las que el aprendizaje, la mejora del proceso de toma de decisiones, la negociación y el consenso, de acuerdo con la Racionalidad Procedimental, es más importante que la búsqueda de una solución óptima, que es el objetivo principal de la Racionalidad Sustantiva clásica (Moreno Jiménez, 1997; Oconnor et al., 1996). Esto está de acuerdo con la nueva concepción de abajo a arriba en las políticas de paisaje, con la participación de los actores locales, y un enfoque transdisciplinario para integrar a los investigadores y académicos con otros actores no académicos, como gerentes, administradores y el público local (Sevenant y Antrop, 2010). ANP permite, por tanto, una evaluación de la sostenibilidad de la agricultura más acorde con la lógica de la Ciencia Post-Normal y la Economía Ecológica (Funtowicz y Ravetz, 1991). Además su aplicación práctica se ve facilitada por el paquete del software Superdecisions (www.superdecisions.com) y diferentes manuales prácticos (Saaty, 2003). Como contrapartida a las fortalezas indicadas, esta metodología presenta una serie de limitaciones que deben ser tenidas en cuenta para una completa comprensión de los resultados obtenidos. Así, existe un acalorado debate en la literatura científica sobre ciertos axiomas y principios de AHP y ANP. La mayor parte de las críticas provienen de las áreas tradicionales de la Teoría de la Decisión y están relacionadas con la independencia y la pertinencia de los objetivos, las comparaciones cualitativas, la representatividad de los juicios, y el carácter abierto/cerrado de los modelos (Parra-López et al., 2008a). También, los métodos multicriterio en general tienen una base teórica más débil que los métodos monetarios, pero ofrecen una mayor flexibilidad al no estar limitados por estrictos requisitos de diseño teóricos basados en la utilidad (Hall et al., 2004). Por otra parte, el modelo agro-ecológico desarrollado para el olivar en base a ANP (artículo 1) contiene algunas simplificaciones y suposiciones, como cualquier modelo, pues no deja de ser una simplificación de la realidad. Por ejemplo, no se analizó como función el cambio climático debido a la falta de información previa y conocimientos de los expertos en el caso del cultivo del olivo. Esto queda pendiente para futuras investigaciones. La validez de nuestro modelo y los resultados se evaluó a través de un contraste a-posteriori con la abundante literatura previa sobre los efectos de las técnicas de cultivo sobre las funciones de este cultivo. Estos estudios previos son, en general, muy específicos, mientras que nuestro trabajo ha aspirado a ser más integrado. También hay que tener en cuenta que el modelo ha sido especificado para las condiciones promedio agroclimáticas, ambientales y socio-institucionales de cultivo del olivo en Andalucía. Sin embargo, el sector es heterogéneo en cuanto a las características estructurales de las explotaciones de olivo, el marco socio-económico, el clima, etc. En otras condiciones, los resultados pueden variar y sería necesario seguir investigando, como en el caso del olivar de montaña.

Por otra parte, ANP en exclusiva (artículos 1 y 2) o combinado con QFD (Quality Function Deployment – Despliegue de la Función de Calidad) (Akao, 1997) (artículo 4), se ha utilizado para definir la relación entre las funciones de no-mercado de los sistemas agrarios y las demandas sociales por la agricultura y determinar los beneficios públicos netos. En lugar de evaluar los equivalentes monetarios de las funciones de no-mercado, lo cual ya se ha indicado que tiene sus críticas en parte de la literatura, nuestro enfoque revela el valor económico de las funciones de no-mercado de los sistemas agrarios analizados como resultado de las preferencias declaradas de los ciudadanos hacia diferentes funciones de la agricultura. Las demandas de los ciudadanos hacia la agricultura se han obtenido en base a una encuesta a 409 ciudadanos, en el caso de Andalucía, y del Eurobarómetro (EC, 2005), en el caso de los Países Bajos, como se ha indicado en la 'Metodología general de la investigación'. QFD es una herramienta analítica para la planificación estratégica cuyo objetivo es trasladar las necesidades de los consumidores, o WHATs, que equivale a las demandas sociales por la multifuncionalidad agraria en nuestra aplicación, en requerimientos estratégicos o técnicos, o HOWs, es decir, cómo pueden satisfacerse estas necesidades, que equivalen a las alternativas técnicas para las prácticas agrarias en nuestro caso. ANP permite paliar algunas limitaciones de la aplicación tradicional de QFD relacionadas con la escala de medida de las relaciones y el tratamiento de las relaciones internas entre WHATs y entre HOWs (Karsak et al., 2003; Partovi, 2001). Una cuestión importante a considerar a nivel metodológico es la validez de los resultados a raíz de la incertidumbre sobre la definición de la demanda del público y las opiniones de los expertos sobre la relación entre funciones y las preferencias públicas. Un análisis de incertidumbre (Rossing et al., 2007) daría información sobre la relación entre las fuentes de variación y su contribución a la incertidumbre en las conclusiones. Por ejemplo, mientras los resultados obtenidos en la Tesis son válidos en el corto plazo, un análisis de series temporales revelaría en qué medida la evolución de la demanda del público influye en los resultados y en la definición de políticas coherentes en el medio y largo plazo.

El modelo agro-ecológico LANDSCAPE Images para la ganadería lechera no fue desarrollado en principio para la Tesis sino adaptado y aplicado al caso de estudio del norte de los Países Bajos. Como novedad se fijaron como objetivos de optimización los beneficios de mercado y no-mercado (artículo 3) y los beneficios privados y públicos (artículo 4). En cualquier caso cabe destacar como una importante fortaleza de este método de optimización multiobjetivo el posibilitar la exploración de nuevas combinaciones de técnicas agrarias y poder delimitar de una forma precisa la frontera de trade-off entre los objetivos de optimización, es decir, entre los beneficios de mercado y no-mercado, y entre los beneficios privados y públicos, de los sistemas agrarios. Dicha frontera permite determinar los paquetes tecnológicos de mayor sostenibilidad. La adaptación del modelo agro-ecológico LANDSCAPE Images realizada en la Tesis permite revelar paisajes agrarios óptimos desde el punto de vista de su sostenibilidad global (alternativas utópicas a promover por las políticas) y paisajes pésimos (alternativas distópicas a disuadir por las políticas). La situación actual de un paisaje agrario formado por varias explotaciones puede ser comparada con diferentes alternativas, incluida la 'óptima socialmente', es decir, la alternativa de uso del suelo que maximiza el beneficio social neto del paisaje dadas las actuales restricciones técnicas y agronómicas a nivel de parcela y explotación, y las características actuales del entorno económico y social. Como debilidades del modelo LANDSCAPE Images habría que citar la escasez de información sobre algunos de los procesos agro-ecológicos a modelizar, su elevada complejidad matemática así como la inexistencia de un software específico. En efecto, el proceso de optimización es ‘NP-complejo' (NP: nondeterministic polynomial time - tiempo polinomial no determinista), es decir, no existe un algoritmo que garantice la obtención de una superficie de trade-off entre objetivos de optimización en todas las circunstancias debido a que la dimensionalidad del problema, y por lo tanto la dificultad computacional, crece más rápido que cualquier polinomio en el número de variables de decisión (Groot et al., 2007). Técnicas heurísticas como los algoritmos genéticos y las estrategias evolutivas pueden ser empleados para obtener aproximaciones de las superficies de trade-off en una población de soluciones (Bergey y Ragsdale, 2005; deVoil et al., 2006; Groot et al., 2007). Hay también que indicar que el modelo LANDSCAPE Images es estático y apropiado para el corto plazo ya que se asumen precios constantes de inputs y outputs. En el caso de un horizonte de tiempo lo suficientemente largo para permitir cambios en los precios sería necesario construir una serie de modelos estáticos para diferentes momentos en el tiempo. Sin embargo, el enfoque estático es suficiente para definir las políticas de paisaje y acuerdos de compensación financiera entre los agricultores en el corto plazo, por ejemplo por 5 años que es el período común en los contratos agroambientales vigentes.

La unidad de análisis del modelo LANDSCAPE Images es el paisaje ya que muchas de las funciones de la agricultura no se pueden desagregar a nivel de explotación, como p.ej. la calidad del paisaje. Esto imposibilita determinar la contribución exacta de cada ganadero a la multifuncionalidad y sostenibilidad global de dicho paisaje lo que dificulta la definición de políticas agrarias equitativas entre los ganaderos. Este problema se ha abordado en la Tesis proponiendo un mecanismo de compensación financiera para la acción colectiva basado en el criterio de Kaldor-Hicks y la mejora de Pareto y así superar los desajustes de escala espacial entre las decisiones de gestión de recursos a nivel de las explotaciones individuales y los objetivos de políticas a nivel de paisaje (artículo 5). El mecanismo propuesto es voluntario para los ganaderos y permitiría incrementar la equidad entre los mismos transfiriendo beneficios de los ganaderos más beneficiados a los más perjudicados por un cambio de prácticas que conlleve un sistema agrario más sostenible a nivel de paisaje. La mejora de la equidad se considera como uno de los atributos fundamentales del desarrollo sostenible (Okey, 1996) y podría reducir los costes de transacción para la implementación de políticas (Vatn, 2002). Experimentos de laboratorio y análisis de casos de estudio (Ostrom, 1990; Ostrom et al., 1994) han demostrado que las personas tienen la capacidad de organizarse y lograr resultados mucho mejores de lo que se predice la teoría económica convencional. En cualquier caso, con el mecanismo propuesto, nadie saldría perjudicado con respecto a la situación inicial antes de que se produzca el cambio hacia un paisaje más sostenible globalmente. Las implicaciones del mecanismo propuesto para el diseño de políticas serán discutidas en mayor detalle en un apartado posterior.

Finalmente, se ha aplicado el marco de los Beneficios Públicos/Privados Netos (BPPN) (Pannell, 2008; Pannell et al., 2012). En este marco metodológico se establece, entre otras condiciones, que no se apoyará financieramente desde las instituciones públicas a aquellas alternativas que no redunden en un mayor bienestar público comparado con la situación de las técnicas implementadas en la actualidad. También se supone que los agentes productores utilizarán una nueva alternativa de producción si les conlleva un beneficio económico/financiero, en la versión básica del modelo. Este modelo se puede refinar para incluir otros costes de transacción, de aprendizaje, etc. (Pannell, 2008). En nuestro caso se ha aplicado la versión básica, suponiendo que el estímulo de cambio de los agricultores es exclusivamente su beneficio financiero. Esto es una simplificación y la inclusión de otros costes y beneficios no monetarios para los agricultores en el análisis podría ser objeto de nuevas investigaciones en el futuro. Partiendo de las técnicas aplicadas en la actualidad es posible determinar el grado de mejora en la sostenibilidad de los sistemas agrarios asociada a otra combinación de técnicas agrarias (paquete tecnológico) en función de los beneficios privados y públicos y determinar el mecanismo político más eficiente en términos de costes (Campbell et al., 2007) para promover o disuadir el cambio de técnicas agrarias. Los mecanismos de política propuestos en el marco BPPN son diversos, incluyendo incentivos positivos y negativos, la acumulación de conocimientos y su difusión (extensión, desarrollo de tecnología) y la inacción informada. El simple desconocimiento por parte de dichos agentes de alternativas de producción innovadoras beneficiosas puede limitar su adopción. Por tanto, el diseño de políticas no ha de basarse exclusivamente en el estímulo/desestímulo financiero en base a subvenciones/penalizaciones de los agricultores, sino que la transferencia de conocimiento y el fomento del desarrollo tecnológico de las empresas agrarias pueden ser de vital importancia. Esto pone de relieve el papel clave de la investigación pública y privada y de la transferencia al sector agrario.

2. Funciones de no-mercado prioritarias de los sistemas agrarios según las demandas sociales

La integración de las preferencias de la sociedad en los modelos de demandas sociales desarrollados tanto para el olivar de Andalucía (artículo 2) como para la ganadería lechera de los Países Bajos (artículos 3 y 4) ha permitido definir las prioridades que las diferentes funciones de ambos sistemas agrarios tienen para la sociedad andaluza y neerlandesa, respectivamente, que esperan una serie de servicios públicos por las subvenciones que recibe la agricultura. Cabe destacar que se han incorporado las demandas de los ciudadanos andaluces (409 entrevistas) y neerlandeses (Eurobarómetro) (European_Commission, 2006), respectivamente, sean consumidores o no de los productos agrarios (aceite de oliva y leche, respectivamente), pues las múltiples funciones de los dos sistemas agrarios, incluyendo muchas externalidades, afectan potencialmente a todos y, por tanto, las demandas de todos deben ser consideradas en la planificación de políticas y estrategias. Si bien el conjunto de actores afectados por un cambio en las funciones de no-mercado se compone potencialmente de todos los ciudadanos del mundo, el impacto en los diferentes grupos puede ser diferente dependiendo entre otros en la proximidad espacial a la procedencia de las funciones de no-mercado. Por razones prácticas se ha considerado la población andaluza y neerlandesa, respectivamente, ya que el impacto de las funciones no comerciales de los sistemas agrarios analizados fuera de las regiones donde se localizan se ha supuesto no significativo.

En el caso del olivar, las principales demandas de la sociedad son la de mantener y crear empleo, seguida de la de mantener la calidad de las aguas y mejorar la gestión de los recursos hídricos, y de la de producir alimentos sanos, seguros y de calidad. Una vez consideradas las interrelaciones entre las demandas de la sociedad y las funciones de no-mercado de los sistemas agrarios, satisfacer estas demandas significaría priorizar una serie de funciones: menor contaminación de las aguas, menor erosión, capacidad de retención de agua y fertilidad del suelo, y biodiversidad. En el caso de la ganadería lechera las principales funciones demandadas a la agricultura son asegurar unos ingresos estables y adecuados para los agricultores, asegurar que los productos agrarios son sanos y seguros, y promover el respeto del medio ambiente. Esto se traduce en una priorización de las funciones de no-mercado, siendo la salud ambiental (proxy de contaminación del suelo) la función más importante, seguida por la calidad del paisaje y, en último lugar, por el valor natural (proxy de biodiversidad). Por tanto, en el diseño de políticas no puede obviarse el importante papel social y ambiental que los sistemas agrarios desempeñan, cuestiones muy valorados por los ciudadanos en general a un nivel similar a las cuestiones económicas. Estos resultados son consistentes con la demanda social en Europa que, en cuestiones clave, opina que los responsables políticos deben prestar la misma atención a las cuestiones ambientales y sociales que a las económicas (EC, 2005).

3. Técnicas y paquetes tecnológicos óptimos

Los resultados obtenidos indican que los olivareros andaluces y ganaderos neerlandeses del norte no están implementando las técnicas agrarias socialmente óptimas, confirmando así la hipótesis de la presente tesis y justificando la necesidad de diseñar políticas públicas eficientes tendentes a promover un cambio efectivo en las técnicas agrarias implementadas por los agricultores y ganaderos. No obstante, como a continuación se detalla, en el caso de Andalucía la 'brecha' en la sostenibilidad es más acusada que en los Países Bajos.

En efecto, en el olivar andaluz, las prácticas actuales están especialmente lejos de ser ambiental y socialmente óptimas. Los agricultores parecen estar alcanzando altos estándares de calidad del aceite (organolépticas, químicas, etc.) y ajustando los costes de producción mientras descuidan en cierta medida las funciones de no-mercado (o externalidades) sociales y, sobre todo, ambientales, de su actividad productiva. Por tanto, si bien se ha comprobado que la evolución de los últimos años ha sido positiva en cuanto a la sostenibilidad de las técnicas empleadas (la sostenibilidad del olivar se ha incrementado en un 15,54%), sobre todo en cuestiones económicas y ambientales, se ha verificado que existe un amplio margen de mejora de las prácticas que se están implementando actualmente. Específicamente, es posible incrementar la competitividad de las explotaciones agrarias y el beneficio de los olivareros, pudiéndose mejorar así el comportamiento económico de las mismas y a la vez mejorar su comportamiento ambiental y social, incrementando de esta forma su sostenibilidad global. Se han detectado las prácticas agrarias más sensibles, es decir, que más influyen en el comportamiento multifuncional de las explotaciones agrarias. Son prácticas a las que deberían ir enfocadas con preferencia las políticas agro-ambientales y estrategias empresariales por la competitividad y sostenibilidad. Así, la práctica que se muestra más influyente en las diferentes funciones es el manejo del suelo. Otras prácticas muy sensibles son el riego (el hecho de regar, más que la forma de hacerlo), la fertilización (incluyendo el modo de aplicación y los fertilizantes usados) y el tratamiento fitosanitario en general (no contra una plaga en concreto o la forma de hacerlo). Las variables relacionadas con la recogida de la aceituna son determinantes para la calidad del producto final y están ligadas a la identidad cultural y el paisaje del cultivo del olivo. En general, los resultados demuestran que técnicas como la cobertura vegetal del suelo, la fertilización orgánica, el análisis de suelo o de hoja antes de la fertilizar, el análisis de la calidad del agua de riego, la fertirrigación, el riego siguiendo asesoramiento técnico y la baja intensidad de la poda se deben promover. Estos resultados están, en general, de acuerdo con la literatura previa, que destaca los beneficios de la cobertura vegetal del suelo para controlar la erosión y la mejora de sus características físico-químicas y biológicas (Fleskens y Stroosnijder, 2007; Francia Martínez et al., 2006; Gómez et al., 2003; Gómez et al., 2002; Gómez et al., 2004; Hernández et al., 2005; Kosmas et al., 1997; Rodríguez-Lizana et al., 2007), la mayor sostenibilidad del olivar de regadío (2011; Gómez-Limón et al., 2011), y la influencia de la fertilización en las funciones económicas y las relacionadas con el suelo (Beltrán et al., 2005; Erel et al., 2008; Fernández-Escobar et al., 2009; Morales-Sillero et al., 2008; Restrepo-Diaz et al., 2008; Tabatabaei, 2006).

El paquete tecnológico, es decir, el conjunto de alternativas técnicas para las prácticas agrarias, que optimiza la función de 'desarrollo rural y empleo', que además está en línea con la principal función de no-mercado demandada por el conjunto de la sociedad andaluza de mantener y crear empleo, presenta el mejor comportamiento multifuncional o de sostenibilidad global de todos los paquetes tecnológicos óptimos analizados (11 óptimos, uno para cada función analizada). Asociado a este máximo encontramos un muy buen comportamiento de la producción y de la calidad de las aceitunas, de las funciones sociales, como el desarrollo rural y el empleo y la identidad cultural y el paisaje, y de las funciones ambientales, especialmente las relacionadas con el estado del suelo y la biodiversidad. Así, este paquete tecnológico representa una alternativa de producción ganadora-ganadora pues tanto el beneficio empresarial para los agricultores como el conjunto de funciones económicas, ambientales y sociales mejorarían si se adoptase por los agricultores. Para alcanzarlo se requiere, además del empleo de cubiertas vegetales (fundamental para alcanzar cualquier óptimo menos el de la calidad), riego, fertirrigación, fertilizantes orgánicos y recogida no mecanizada de la cosecha. Como posibles trabas a su adopción se pueden considerar, además del consumo de agua que no siempre es posible, y el mayor coste debido al riego y la recogida manual de la cosecha fundamentalmente, si bien los beneficios globales compensarían, como se acaba de señalar. Los resultados también indican que las explotaciones olivareras adoptantes del paquete tecnológico modal de la Producción Integrada, regulada en Andalucía por la Orden de 15 de abril de 2008 (BOJA num.83), presentan un comportamiento multifuncional superior a las no adoptantes (un 39% globalmente), especialmente en los impactos ambientales, que mejoran hasta casi un 200% en algunas funciones como la biodiversidad o la fertilidad del suelo, y en los costes de producción y la producción de aceituna, que mejoran un 58% y un 66% respectivamente. Esta superioridad desde el punto de la sostenibilidad del olivar integrado frente al convencional está en acuerdo con diversos trabajos previos (Parra-López et al., 2007, 2008a). Las explotaciones integradas mayoritariamente implementan cubierta vegetal, aplican los fertilizantes directamente en suelo, realizan los tratamientos fitosanitarios al sobrepasar un umbral de infestación o según consejo del experto, y la recogida de la aceituna del suelo es más mecanizada que manual. Por el contrario, la adopción del paquete tecnológico asociado a DOP no está asociado a una mejora significativa de la sostenibilidad global (un 1%) pues la única diferencia con relación a las que no tienen denominación de origen es la aplicación de fertilizantes en suelo. Otros Sistemas de Calidad Certificada, como la agricultura ecológica, no han podido ser evaluados multifuncionalmente debido a la escasez de olivicultores implementándolos actualmente. No obstante, otros trabajos previos confirman la superioridad multifuncional del olivar ecológico en Andalucía frente al convencional (Parra-López et al., 2007, 2008a). La forma de agricultura intensiva también ha demostrado ser más sostenible que la agricultura convencional en el olivar (un 54% globalmente). En efecto, las técnicas diferenciadoras de una olivicultura más integrada son el uso de cubierta vegetal y el riego. Estas técnicas tienen un efecto muy positivo en casi todas las funciones, coincidiendo con estudios anteriores (Gómez-Limón et al., 2011). Así, una producción intensiva incrementa sustancialmente la producción del olivar (99%), y es superior desde el punto de vista del medio ambiente, sobre todo en cuanto a la biodiversidad y las propiedades del suelo, con la lógica excepción de su pobre desempeño en la función de un menor consumo de agua. Es también mejor en términos sociales, contribuyendo al desarrollo rural y el empleo y para la identidad cultural y el paisaje.

En el caso de la ganadería lechera del norte de los Países Bajos, los resultados indican que aunque existe, no hay tanto margen para la mejora de la situación actual en términos de beneficio social neto pues las prácticas actuales se encuentran bastante próximas a las óptimas socialmente. Esto puede deberse a las estrictas políticas ambientales de la última década (Henkens y Van Keulen, 2001) que han promovido un menor uso de insumos y bajos niveles de emisiones. Alcanzar el óptimo social implica mejorar la calidad del paisaje, aún a costa de un ligero detrimento de las funciones de valor natural (proxy de biodiversidad) y la salud ambiental (proxy de contaminación del suelo), y una mejora del margen bruto de los ganaderos (de un 1%) con menos subsidios (65% menos que en la situación actual). Las técnicas agrarias que incrementan la variación en el número de especies de plantas en los pastizales y la irregularidad en el patrón de los setos son las que más inciden en la calidad del paisaje y son las que se deben promover. Estos resultados deben ser interpretados con precaución debido a que la zona de estudio de caso seleccionada es de pequeña escala (Northern Frisian Woodlands) y en ella los ganaderos están especialmente comprometidos con la protección ambiental y la conservación y mejora del paisaje. Otra consideración a tener en cuenta es que las funciones de no-mercado consideradas en el caso de los Países Bajos son esencialmente ambientales, no incluyendo cuestiones sociales dada la falta de información sobre las mismas. Esto puede afectar a la comparación con los resultados del olivar en Andalucía. Por otra parte, en los modelos de demanda social en los Países Bajos se ha supuesto que cambios relativos similares en los beneficios netos de mercado y no-de mercado tienen la misma influencia en el bienestar social. Esta suposición está, en cualquier caso, de acuerdo con la demanda social en los Países Bajos (EC, 2005; European_Commission, 2005), que considera que se debe prestar la misma atención o más a las cuestiones ambientales que a las económicas, y con otros estudios relacionados con la sostenibilidad de los sistemas agrícolas lácteos neerlandeses (van Calker et al., 2008; van Calker et al., 2006). A parte de alcanzar el óptimo social, otros criterios diferentes al beneficio social se podrían utilizar para seleccionar los agro-paisajes más deseables. Algunos de esos criterios pueden ser la maximización del coste-beneficio de las alternativas, la minimización de costes, etc. En la práctica, el apoyo público puede estar condicionado por la disponibilidad de recursos y las preferencias ideológicas de los políticos o grupos de influencia, o simplemente por la inercia de las políticas existentes (Harvey, 2003).

4. Políticas públicas por la multifuncionalidad y la sostenibilidad

Desde una perspectiva de diseño de políticas, si la UE desea mantener el principio de 'el dinero público para bienes públicos' y promover una agricultura verde, la PAC debería abandonar un modelo de pagos directos no focalizados y promover pagos y el apoyo a las técnicas de cultivo específicas que demuestren un elevado potencial para obtener beneficios ambientales y sociales. En este sentido, sería importante distinguir entre buenas prácticas agrícolas obligatorias (condicionalidad) y prácticas específicas que promueven unos beneficios económicos, sociales o ambientales superiores que deben ser pagados o promovidos (Gómez et al., 2004). Como ya se ha indicado, en el caso del olivar de Andalucía, técnicas tales como la cobertura del suelo, la fertilización orgánica, el análisis de suelo o de la hoja antes de la fertilización, el análisis de la calidad del agua de riego, la fertirrigación, el riego siguiendo asesoramiento técnico y la poda de baja intensidad, han demostrado que implementadas individual o conjuntamente conllevan unos índices de sostenibilidad global superior de los sistemas olivareros y se deben promover. Las prácticas asociadas a la Producción Integrada también han demostrado una mayor sostenibilidad. Se trata de técnicas para el cuidado del suelo, agua y biodiversidad, temas muy demandados por la sociedad como nuestros resultados muestran, con un efecto directo muy relevante sobre las funciones medioambientales y un efecto indirecto sobre las funciones económicas y sociales del cultivo del olivo. La olivicultura intensiva, que promueve el uso de la cubierta vegetal y el riego, también ha demostrado ser más sostenible. No obstante, la adopción del riego puede verse dificultada o impedida por la disponibilidad de agua. Por tanto, políticas de infraestructuras que promuevan el riego también deberían potenciarse, lo que concuerda con otros estudios (Villanueva et al., 2014). El resto de prácticas no deberían presentar problemas técnicos para ser implementadas. En el caso de la ganadería del norte de los Países Bajos, las técnicas tendentes a incrementar el número de especies de plantas en los pastizales y la irregularidad en el patrón de los setos deben ser promovidas según nuestros resultados. En ambos sistemas agrarios, las políticas públicas deberían eliminar o reducir las barreras financieras, técnicas y de información y otros costes de transacción, que impiden que los agricultores adopten técnicas agrícolas más sostenibles. Las políticas no deben limitarse a las medidas financieras dirigidas a los agricultores, como los pagos verdes y los programas agroambientales. De hecho, los resultados ponen de manifiesto que el mecanismo de política agraria más eficiente para lograr la mayor sostenibilidad global, en el marco de la planificación costo/eficiente (Campbell et al., 2007) y el marco de los Beneficios Públicos/Privados Netos (BPPN) (Pannell, 2008; Pannell et al., 2012), es la extensión tanto en el olivar andaluz como en la ganadería neerlandesa, es decir, la transferencia de tecnología, la educación, la comunicación, las demostraciones, el apoyo a las redes comunitarias, etc. Es necesario concienciar a los agricultores de los beneficios económicos, sociales y ambientales de la implementación de paquetes tecnológicos óptimos socialmente. Esto pone de relieve la importancia de reforzar el apoyo institucional, sin inyectar necesariamente recursos monetarios adicionales, y la pertinencia de ciertos agentes de I+D+i como los Centros Públicos de Investigación y organismos de formación. Esto está en consonancia con algunas medidas de desarrollo rural de la nueva PAC (EC, 2013) que tratan de promover: 1) la innovación, mediante la fomento de una mayor cooperación entre la agricultura y la investigación a fin de acelerar la transferencia de tecnología a los agricultores; 2) el conocimiento, mediante la potenciación de la función de los servicios de asesoramiento agrícola; y 3) la cooperación, mediante la promoción de proyectos piloto y de los contratos conjuntos entre los agricultores o grupos de agricultores y las administraciones públicas para la prestación de servicios ambientales, tales como los contratos territoriales.

Los resultados también ponen de manifiesto que el margen de mejora de la sostenibilidad y el rango de alternativas técnicas más sostenibles en el olivar de Andalucía es mayor que en la ganadería lechera neerlandesa. En efecto, en el olivar los beneficios sociales pueden ser maximizados a través de dos estrategias muy diferentes en consonancia con la reconocida naturaleza dual productiva/multifuncional de la producción de aceituna en Andalucía y las ayudas de la PAC (Gallardo et al., 2003): 1) por la maximización de los beneficios privados de los agricultores, lo cual es un objetivo importante para los productores orientados a la productividad y la eficiencia en el marco del primer pilar de la PAC; y 2) mediante la maximización de beneficios públicos, lo que es una mejor estrategia para los productores orientados a las preocupaciones medioambientales y de desarrollo rural del segundo pilar. En ambos casos, con la promoción de las técnicas adecuadas para cada uno de ellos, sería posible alcanzar niveles muy elevados de sostenibilidad. Esto demuestra que, para el olivar, la maximización de los beneficios sociales no es contradictorio con la mejora de los beneficios privados de los agricultores. En el caso de la ganadería del norte de los Países Bajos se ha constatado, por el contrario, un marcado trade-off entre las funciones privadas y públicas. En efecto, el desarrollo técnico del sector parece mucho más avanzado en el sentido de que actualmente se están utilizando prácticas bastante optimizadas desde el punto de su comportamiento económico y ambiental. Una política dirigida a promover un cambio hacia un sistema más sostenible debe ser más dirigida a unas prácticas concretas que mantengan el equilibrio entre los beneficios privados de los agricultores y los beneficios del resto de agentes. Es decir, debe ser una política de filosofía híbrida productiva/multifuncional. Desviarse de estas técnicas puede conllevar un marcado detrimento de alguno de los dos grupos de interés. En cualquier caso, es importante tener en cuenta que estos resultados se obtuvieron para las condiciones promedio agroclimáticas, ambientales y socio-institucionales de cultivo del olivo en Andalucía y para una región concreta de agricultores de los Países Bajos con sistemas ganaderos intensivos pero a la vez especialmente sensibles con la preservación del medio ambiente. Los resultados podrían variar en otras condiciones y sería necesario investigar más a fondo con el fin de extrapolar conclusiones más generales para el diseño de políticas.

En el caso de los Países Bajos se aborda el problema de la escala espacial en el diseño de políticas agrarias. Los análisis realizados indican que las políticas diseñadas a nivel de paisaje pueden ser más sostenibles globalmente a nivel de paisaje en términos de beneficios públicos y privados agregados, pero pueden ser inaceptables para algunos agricultores pues les pueden acarrear pérdidas económicas/financieras. El caso contrario también se ha detectado, es decir, beneficios privados para unos pocos agricultores podrían conducir a resultados indeseables para los demás agricultores y para la sociedad. En efecto, si bien las decisiones sobre las técnicas agrarias que emplean los ganaderos las toman a nivel de parcela o explotación, las funciones de la agricultura pueden producirse también a nivel de paisaje. Un ejemplo de ello es la calidad del paisaje, a la cual contribuyen todos los agricultores, pero sobre la cual es difícil discernir la contribución exacta de cada uno de ellos. En estos casos las políticas deben promover la acción colectiva. Así, se ha propuesto un mecanismo de acción colectiva cuyo fin sería la adopción real por parte de todos los ganaderos de las técnicas más sostenibles a nivel de paisaje. Este mecanismo consiste en una posible, aunque no siempre necesaria, compensación económica entre agricultores basada en el principio de que nadie se vea perjudicado económicamente con un cambio de técnicas y se pueda alcanzar un sistema más sostenible a nivel de paisaje. La implementación del mecanismo de compensación propuesto podría ser llevada a cabo a través de instituciones informales, como el acuerdo verbal entre los agricultores, o formales, como a través de formas contractuales entre agricultores y la administración como ya se está produciendo en las cooperativas ambientales de los Países Bajos. Para la implementación práctica del mecanismo de compensación propuesto se requiere un cierto grado de solidaridad de los ganaderos entre sí y con la sociedad en general para alcanzar configuraciones de paisaje más sostenibles, objetivo en plena armonía con la razón de ser y el origen de las Cooperativas Ambientales de los Países Bajos analizadas (Renting y Van Der Ploeg, 2001). Recientemente, varias Cooperativas Ambientales se han fusionado para crear una cooperativa regional, que tiene como objetivo establecer contratos con el gobierno según los cuales los agricultores participantes son recompensados (o penalizados) como grupo por alcanzar (o no alcanzar) los objetivos medioambientales especialmente relacionados con la biodiversidad y el paisaje. Promover la concienciación ambiental y social para la acción colectiva de los agricultores en el caso de otros sistemas agrarios, como el olivar de Andalucía, es por tanto uno de los grandes retos para promover una agricultura más sostenible. Por otra parte, las políticas agroambientales basadas en la acción colectiva no han sido hasta ahora muy utilizadas en la UE, pero se han generalizado en Australia, Nueva Zelanda y Canadá. En este sentido, los proyectos dirigidos por la comunidad, en la que los agricultores suelen jugar un papel importante, pueden ayudar a construir el capital social, promover el trabajo cooperativo y obtener beneficios ambientales a una escala más amplia que la de una explotación individual (Keenleyside et al., 2009). Un elemento crucial para estimular y mantener el comportamiento cooperativo es la comunicación y la capacidad de los participantes para desarrollar y aplicar un sistema de control y sanción (Fuller, 2009; Ostrom et al., 1994). Las relaciones de confianza entre agricultores mutuas son fundamentales, ya que es esencial que cada agente está convencido de que los demás también reducirán el uso del recurso común (Janssen y Ostrom, 2006; Marshall, 2004). La descentralización de las tomas de decisiones y su toma a nivel local también está relacionada con una mayor disposición de los agricultores a cooperar en programas ambientales (Keenleyside et al., 2009; Marshall, 2009). Como debilidad del mecanismo de compensación propuesto cabe citar la necesidad de información sobre características físicas, ecológicas y geográficas a nivel de parcelas, que puede ser difícil de obtener para amplias regiones. Quizá por ello hasta ahora rara vez se ha tomado en cuenta en el desarrollo de esquemas de gobernanza (Bateman, 2009; Renting y Van Der Ploeg, 2001). Esto requeriría un esfuerzo de monitorización catastral cuyos costes de transacción deberían ser evaluados e incorporados a la hora de comparar el mecanismo propuesto con otros posibles mecanismos institucionales de acción colectiva. La definición y promoción de formas eficientes de acción colectiva desde la Administración y el sector privado en el caso del olivar de Andalucía también sería necesaria para alcanzar mayores cuotas de sostenibilidad de la actividad agraria, lo cual debería ser investigado en detalle en futuros trabajos.

Hay que indicar que el diseño de políticas es un proceso dinámico y debe ser planificado en el largo plazo. En efecto, si bien la definición de prácticas y paquetes tecnológicos óptimos y la selección de las políticas adecuadas para promover su adopción se hacen en el corto plazo con respecto a las condiciones actuales (biofísicas, agroclimáticas, socioculturales, tecnológicas, etc.), la implementación de estas prácticas y paquetes tecnológicos óptimos exigirá un esfuerzo a largo plazo para que el sistema biológico pueda adaptarse a las nuevas prácticas de gestión y, finalmente, prestar los servicios previstos. Por lo tanto, el marco que se ha desarrollado en este trabajo debe formar parte de un enfoque de desarrollo de políticas adaptativo (Walker et al., 2001). Este enfoque propone un proceso continuo e iterativo de desarrollo adaptativo orientado a objetivos (Rossing et al., 2007; von Wirén-Lehr, 2001). Tras implementar las políticas propuestas se deberían monitorizar los cambios en los agroecosistemas para seguidamente realizar una nueva ronda de selección de prácticas y políticas adecuadas en las nuevas condiciones de los agroecosistemas, la técnica y la sociedad.

Finalmente hay que subrayar que las políticas agrarias, básicamente orientadas al estímulo de la producción, que son en las que se ha centrado esta Tesis Doctoral, deben ir acompañadas de otras políticas orientadas a estimular la demanda, promocionar y educar a los consumidores sobre la calidad del aceite de oliva, la multifuncionalidad y la sostenibilidad de la agricultura. En efecto, el conocimiento y consumo de aceites de calidad y calidad certificada no es muy alta por parte de los consumidores de

Andalucía si bien se prevé que se incrementará a nivel internacional (Hinojosa-Rodríguez et al., 2014). La educación de la población y la promoción en este sentido se revela como crucial para potenciar el desarrollo de unos sistemas agrarios más competitivos y sostenibles.

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CONCLUSIONES GENERALES

Conclusiones generales

1. Actualmente no se están implementando por parte de los ganaderos lecheros del norte de los Países Bajos ni, sobre todo, por parte de los olivareros de Andalucía, las técnicas agrarias más económica, ambiental y socialmente sostenibles, lo cual confirma la hipótesis de partida de la Tesis. Esto justifica la necesidad de diseñar políticas agrarias y agro-ambientales eficientes tendentes a promover un cambio efectivo en las técnicas agrarias implementadas por los agricultores y ganaderos. Es necesario considerar en el diseño de políticas los beneficios y costes privados y públicos de todas las partes interesadas, así como las funciones de mercado y no-mercado de los sistemas agrarios.
2. Los olivareros andaluces están aplicando alternativas técnicas que son óptimas para la obtención de un producto de alta calidad, pero hasta cierto punto están descuidando los impactos sociales y, en mayor medida, el impacto ambiental de su actividad. A pesar de la evolución positiva en la última década, todavía hay mucho margen de mejora.
3. En el caso del olivar, un mejor desempeño económico no es incompatible con los objetivos sociales, tales como el desarrollo rural y el empleo, y con la protección del medio ambiente del suelo, el agua y la biodiversidad. Es decir, la maximización de los beneficios privados no es incompatible con la de los públicos.
4. Técnicas tales como la cobertura del suelo, la fertilización orgánica, el análisis de suelo o de la hoja antes de la fertilización, el análisis de la calidad del agua de riego, la fertirrigación, el riego siguiendo el asesoramiento de expertos y la poda baja intensidad deben ser objetivos de las políticas públicas que promueven la sostenibilidad en el olivar.
5. En olivar, el paquete tecnológico asociado a la optimización de la biodiversidad es el más sostenible y debería ser promovido desde las administraciones. El paquete asociado al desarrollo rural y empleo, que además está en línea con la principal función de no-mercado demandada por el conjunto de la sociedad andaluza de mantener y crear empleo, es muy equilibrado en la consecución de objetivos privados y públicos. La producción integrada y la agricultura intensiva son paquetes tecnológicos alternativos también de mayor sostenibilidad que las técnicas habituales actuales en la olivicultura andaluza.
6. Los ganaderos neerlandeses están aplicando técnicas más avanzadas desde el punto de vista de su eficiencia económica y ambiental y el margen de mejora de la sostenibilidad de los sistemas agrarios es reducida. Al contrario que en el olivar, la maximización de los beneficios privados es menos compatible con la de los públicos. Esto puede deberse a las estrictas políticas ambientales de la última década y la especial concienciación ambiental de los ganaderos de la zona de estudio.
7. Las técnicas agrarias que incrementen la variación en el número de especies de plantas en los

pastizales y la irregularidad en el patrón de los setos son las que más inciden en la calidad del paisaje y son las que se deben promover por las políticas públicas en el caso de la ganadería neerlandesa.

8. La adopción de los paquetes tecnológicos óptimos socialmente en la ganadería neerlandesa conllevarían unos mayores beneficios para los ganaderos aún con niveles más bajos de subvenciones, y una gran mejora de la calidad del paisaje, si bien implicarían un ligero impacto negativo en la biodiversidad y la contaminación del suelo.
9. El mecanismo de política más eficiente, tanto en el olivar andaluz como en la ganadería neerlandesa, es la extensión agraria, es decir, la transferencia de tecnología, la educación, la comunicación, las demostraciones y el apoyo a las redes comunitarias. Es necesario concienciar a los agricultores de los beneficios económicos, sociales y ambientales que su actividad puede generar. En este contexto, la función de transferencia de conocimiento de las instituciones de I+D públicas, centros tecnológicos y universidades es esencial. Ésta, parece pues, una actuación común a nivel de planificación de políticas públicas por la multifuncionalidad y la sostenibilidad con vocación suprarregional y suprasectorial
10. Cuando existen funciones de los sistemas agrarios a nivel de paisaje que no son agregativas de las de las explotaciones agrarias, como en el caso del paisaje de la ganadería neerlandesa, es necesario definir mecanismos institucionales que fomenten la cooperación entre los agricultores para el manejo de los recursos naturales. El mecanismo de compensación financiera entre agricultores propuesto pretende contribuir a una mayor equidad entre los agricultores y se debe basar en la confianza mutua, la comunicación y la capacidad de control y sanción, y la descentralización de la toma de decisiones y su toma a nivel local.
11. La implementación del mecanismo propuesto, o de otros alternativos en otras condiciones como el olivar andaluz, podría conseguirse a través de instituciones informales, como el acuerdo verbal entre los agricultores, o formales, como las formas contractuales o medidas específicas dentro de los programas agroambientales que promovieran y apoyaran los mecanismos institucionales de gestión de los recursos naturales basados en la cooperación.
12. Este trabajo ha pretendido contribuir teóricamente al campo de la evaluación de la multifuncionalidad y sostenibilidad de la agricultura, la maximización del bienestar social, y el diseño de políticas públicas, desarrollando un marco metodológico integrado que combina la valoración económica, la modelización integrada, el análisis de las partes interesadas y la evaluación multicriterio. El marco metodológico ha demostrado su validez y aplicabilidad para dos sistemas agrarios de elevada relevancia en sus regiones pero muy diferentes entre sí. Sus fundamentos teóricos y metodológicos son lo suficientemente amplios y flexibles como para que sea aplicable también en otros sistemas y condiciones.

Lista de publicaciones asociadas a la investigación realizada

1. Artículos en revistas

Carmona-Torres, C.; Parra-López, C.; Sayadi, S.; Chirosa-Ríos, M. (en revisión). "A public/private benefits framework for the design of polices oriented to sustainability in olive growing". Land Use Policy.

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Parra-López, C.; Groot, J.C.J.; Carmona-Torres, C.; Rossing, W.A.H. (2008). "Integrating public demands into model-based design for multifunctional agriculture: An application to intensive Dutch dairy landscapes". Ecological Economics, 67(4): 538-551. http://dx.doi.org/10.1016/j.ecolecon.2008.01.007

2. Artículos de congresos

Carmona-Torres, C.; Parra-López, C.; Sayadi, S.; Hinojosa-Rodríguez, A.; Erraach, Y. (2011). "Olive farming practices and their multifunctional impacts in the south of Spain". Olivebioteq 2011: International Conference for Olive Tree and Olive Products. Chania, Crete, Greece. 31 oct. – 4 nov. Libro de Proceedings editado con ISBN 978-618-80367-2-7, 978-618-80367-3-4. Contributed paper, presentación oral. Programa disponible en: http://www.nagref-cha.gr/olivebioteq/index_htm_files/OLIVEBIOTEQ_Schedule_v2.pdf

Carmona Torres, C.; Parra López, C.; Sayadi, S.; Hinojosa Rodríguez, A. (2011). "Multifunctional impacts of the olive farming practices in Andalusia, Spain: An analytic network approach". XIII EAAE (European Association of Agricultural Economists) Congress "Change and Uncertainty:

Switzerland. Poster paper, presentación oral. Publicado on-line: http://ageconsearch.umn.edu/bitstream/114319/2/Carmona-Torres_Carmen_233.pdf.

Parra López, C.; Groot, J.C.J.; Carmona Torres, C.; Rossing, W.A.H. (2008). "Exploring sustainable technical alternatives for Dutch dairy systems by integrating agro-economic modelling and public preferences assessment". XIIth Congress of the European Association of Agricultural Economists (EAAE) "People, Food and Environments: Global Trends and European Strategies". 26-29 August. Ghent, Belgium. Libro de actas (resúmenes ponencias): ISBN 978 90 809 1590 9 (p.276); CD (ponencias completas): editado sin ISBN. Publicado on-line por AgEcon Search – Research in Agricultural and Applied Economics: http://purl.umn.edu/44253. Contributed paper, presentación oral.

Parra López, C.; Groot, J.C.J.; Carmona Torres, C.; Rossing, W.A.H. (2008). "Integración de la modelización bioeconómica y el análisis de preferencias sociales en el diseño de innovaciones técnicas sostenibles en agricultura". III Congreso de la Asociación Hispano-Portuguesa de Economía de los Recursos Naturales y Ambientales (AERNA). Palma de Mallorca. 4-6 junio de 2008. Actas editadas en CD sin ISBN. Publicado on-line: http://www.uibcongres.org/imgdb//archivo_dpo4226.pdf. Contributed paper, presentación oral.

3. Documentos técnicos

Carmona-Torres, C.; Sayadi, S.; Parra-López, C. (2009). "Revisión bibliográfica sobre multifuncionalidad de los sistemas agrarios y agroalimentarios". Proyectos P07-SEJ-03121 (MULTIOLI) y RTA2008-00024-00-00 (ECOINNOLI). Documento de trabajo. Consejería de Agricultura y Pesca. Junta de Andalucía. Granada, España.

Fe de erratas en artículos publicados

A continuación se relacionan las erratas detectadas en los artículos publicados y que han sido corregidos en el presente documento de Tesis Doctoral.

Errata 1

En Artículo 3, 3.1. The QFD/ANP methodologies, página 134

Se elimina la "G" subíndice del vector W_P.

Antes:

Firstly, the vector of priorities of the social preferences is calculated considering the inner dependencies according to $\mathbf{w}_{\mathbf{P}}^{\mathbf{int}} = \mathbf{W}_{\mathbf{P},\mathbf{P}} \times \mathbf{w}_{\mathbf{P},\mathbf{G}}$ Secondly, the matrix of priorities of the non-market functions as determined by the social preferences is calculated considering the inner dependences among the non-market functions: $\mathbf{W}_{\mathbf{F},\mathbf{P}}^{\mathbf{int}} = \mathbf{W}_{\mathbf{F},\mathbf{F}} \times \mathbf{W}_{\mathbf{F},\mathbf{P}}$. Finally, the priorities of the functions considering all the interdependencies are calculated: $\mathbf{w}_{\mathbf{F}} = \mathbf{W}_{\mathbf{F},\mathbf{P}}^{\mathbf{int}} \times \mathbf{w}_{\mathbf{P},\mathbf{G}}^{\mathbf{int}}$.

Corregido:

Firstly, the vector of priorities of the social preferences is calculated considering the inner dependencies according to $\mathbf{w}_{\mathbf{P}}^{\mathbf{int}} = \mathbf{W}_{\mathbf{P},\mathbf{P}} \times \mathbf{w}_{\mathbf{P}}$. Secondly, the matrix of priorities of the non-market functions as determined by the social preferences is calculated considering the inner dependences among the non-market functions: $\mathbf{W}_{\mathbf{F},\mathbf{P}}^{\mathbf{int}} = \mathbf{W}_{\mathbf{F},\mathbf{F}} \times \mathbf{W}_{\mathbf{F},\mathbf{P}}$. Finally, the priorities of the functions considering all the interdependencies are calculated: $\mathbf{w}_{\mathbf{F}} = \mathbf{W}_{\mathbf{F},\mathbf{P}}^{\mathbf{int}} \times \mathbf{w}_{\mathbf{P}}^{\mathbf{int}}$.

Errata 2

En Artículo 5, 2.1. Multi-criteria design and evaluation of natural resource management activities in landscapes, página 194

Se elimina la "E" de la variable $\Delta U_{NM,i}$

Antes:

Where $\Delta U_{NM,Ei}$ represents non-market benefits associated with the non-market ecosystem service E_i. $E_i(s)$ and $E_i(0)$ are the landscape performances in the non-market function E_i for a new situation (s) and for the current situation (0), respectively.

Corregido:

Where $\Delta U_{NM,i}$ represents non-market benefits associated with the non-market ecosystem service E_i. $E_i(s)$ and $E_i(0)$ are the landscape performances in the non-market function E_i for a new situation (s) and for the current situation (0), respectively.