Desarrollo de herramientas para evaluar los efectos de los espacios naturales y seminaturales sobre la salud en el contexto de adaptación al cambio climático

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RESUMEN

La promoción de entornos naturales y seminaturales implica una serie de costes económicos, incluyendo tanto costes financieros como de oportunidad. Por ello es necesario el desarrollo de herramientas y metodologías que ayuden a planificadores y promotores de políticas públicas alcanzar una visión global de los costes y beneficios que se derivan de estas medidas, para así tomar decisiones tan cercanas como sea posible al óptimo en términos de eficiencia. Para lograrlo, deben incluirse también los impactos que tienen los espacios naturales y seminaturales sobre la salud, tanto cuando son positivos como cuando tienen un efecto negativo.

Debe tenerse en cuenta también que en el contexto en el que se desenvuelve este estudio desempeña un rol primario el cambio climático. Se trata de un factor relevante por una serie de razones. En primer lugar, por sus potenciales impactos sobre la salud y el bienestar. Uno de los impactos más importantes del aumento global de las temperaturas es la mayor incidencia de fenómenos atmosféricos que desemboquen en inundaciones debido a que éstas suponen una amenaza directa al ser capaces de causar lesiones físicas, secuelas mentales o la pérdida de vidas humanas. Sin embargo, la incidencia de olas de calor, los cambios en la distribución de vectores de enfermedades como los mosquitos, le escasez de agua, etc. pueden tener efectos adversos sobre la salud de las personas. No menos importante es considerar la correlación entre emisiones de gases de efecto invernadero y la presencia en la atmósfera urbana de contaminantes que suponen un riesgo también directo a la salud.

Es por ello que las estrategias de adaptación al cambio climático (así como las estrategias de mitigación en su ámbito) deben considerar la necesidad de proteger la salud de las personas entre sus objetivos prioritarios. En este sentido, fomentar las áreas naturales y seminaturales en entornos urbanos y periurbanos ha sido considerada como estrategia de adaptación. Estas áreas tienen la capacidad de reducir el estrés térmico causado por el efecto isla de calor urbana, lo que las convierte en una forma de proteger a los habitantes de una zona del aumento en las temperaturas. Asimismo, estas zonas evitan el exceso de impermeabilización del terreno que agrava el riesgo de inundación, generando zonas de retención del agua que protejan en este caso no solo a las personas sino también al medio ambiente.

Este trabajo utiliza diversas metodologías para estimar los beneficios en la salud humana de tales entornos, así como los resultados de su aplicación. A continuación, se resumen estas metodologías, así como los resultados obtenidos en cada uno de los segmentos que conforman este estudio.

El nexo entre cambio climático, servicios ecosistémicos y salud humana: hacia un marco conceptual

<u>(The nexus between climate change, ecosystem services and human health: Towards a conceptual framework)</u>

El primero de los estudios desarrollados en este trabajo se enfoca en el impacto que alteraciones en el entorno natural pueden generar en la salud y el bienestar de las personas, con especial atención a los potenciales beneficios complementarios que los espacios verdes puedan generar al ser promovidos como forma de adaptación al cambio climático. Contabilizar estas externalidades, tanto cuando son positivas como en el caso de que resultaran en perjuicios, es necesario de cara a evitar una subestimación de los beneficios totales de las medidas tomadas, asociada a una provisión subóptima en la planificación, particularmente en entornos urbanos.

Para acercar una visión coherente de la cuestión, el estudio propone un marco conceptual construido en base al modelo eDPSEEA (ecosystem-enriched Driver, Pressure, State, Exposure, Effect, Action). A través de este modelo se pretenden clarificar las interacciones entre espacios verdes y salud humana sin pasar por alto el rol del cambio climático en la ecuación, puesto en este caso como fuerza motora principal.

Partiendo del modelo eDPSEEA, el marco propuesto se fundamenta en los resultados de una revisión de la literatura, descrita en el propio capítulo, centrada en las interrelaciones entre ecosistema y salud, tanto para buscar las principales teorías que tratan de explicar estos impactos como para buscar los datos empíricos existentes. Será este último grupo de estudios, el que agrupa a las investigaciones que cuentan con datos empíricos, del que se extraerán los datos cuantitativos necesarios para el análisis realizado para el siguiente capítulo.

El trabajo realizado en este capítulo de la tesis halla evidencias claras en la literatura basada en la perspectiva del ecosistema de una asociación entre el clima, la salud y los espacios verdes; mientras que los resultados presentes en la literatura centrada en la perspectiva sanitaria mostraban mayores variaciones en los resultados. Esta revisión de la literatura encontró numerosos estudios analizando el tema (117 en el momento de completar el capítulo), si bien con un rango amplio de metodologías y resultados, incluyendo revisiones de la literatura previas, estudios de corte cualitativo, tesis doctorales, estudios experimentales en entornos controlados, etc. El patrón aparente de la literatura se inclina hacia la existencia de beneficios potenciales en la salud y el bienestar de las áreas verdes. Sin embargo, estos beneficios podrían estar restringidos a entornos urbanos o con una determinada densidad poblacional, puesto que los estudios realizados en entornos rurales eran menores en cantidad y de resultados más variados. Otro caso particular es el de las alergias. puesto que la cantidad de estudios dedicados a dilucidar si el contacto con la naturaleza empeora el bienestar o evita la aparición de alergias es escaso y queda fuera del alcance de este análisis.

La propia revisión de la literatura constató la necesidad de un cuerpo científico mayor a la hora de dilucidar los impactos de las áreas verdes y la salud, conclusión repetida en varios estudios, pero también alcanzada al observar la gran variabilidad en metodologías y resultados. Promover esta investigación, particularmente la desarrollada en términos cuantitativos que pueda ayudar a estimaciones más precisas de las externalidades de las áreas verdes sobre la salud es uno de los objetivos de este artículo. El principal objetivo de esta sección es precisamente la de crear un marco adecuado para el uso en estudios multidisciplinares y fomentar el debate entre distintos sectores y agentes implicados.

Exposición a las áreas verdes: Modelizando los beneficios en la salud en un contexto de heterogeneidad en los estudios

(Exposure to green areas: Modelling health benefits in a context of study heterogeneity)

La heterogeneidad descrita en la revisión de la literatura incluida en el capítulo anterior es la motivación principal del análisis descrito el tercer capítulo. Tal diversidad no sólo se ciñe a los resultados, sino que también afecta a las metodologías empleadas y a los aspectos sanitarios y medioambientales analizados, complicando así el análisis estadístico de los resultados globales. Homogeneizar los resultados de los análisis existentes es una labor necesaria y compleja. Esta es sin embargo una tarea pendiente, puesto que sin ella resulta imposible atajar la cuestión de una manera adecuada.

La existencia de una variedad de factores ambientales y socioeconómicos que modulan los resultados es uno de los ejes fundamentales de este trabajo que se presenta en el tercer capítulo de esta tesis. Por ello el análisis considera una serie de variables contextuales que son agregadas a los datos recopilados en la literatura para así afinar el resultado obtenido. De esta forma, a los datos ofrecidos en el estudio sobre resultados y población, se agregan datos referidos al entorno en el que se realizó el estudio, tales como renta del país en el que se realizó, nivel de alfabetismo o distribución generacional de la población. Entre los datos recogidos de cada estudio se encontraban los propios resultados y cuestiones referidas al tipo de impacto en la salud que se estaba registrando, para lo cual se distinguió entre estimaciones subjetivas (declaradas) y objetivas (establecidas por expertos externos); mortalidad y morbilidad; y tipología sanitaria (salud general, cardiovascular, respiratoria, mental, otras afecciones).

Asimismo, para evitar el potencial sesgo que causaría la existencia de resultados significativos y no significativos en la literatura, se emplea un sistema de selección muestral, el conocido como modelo de Heckman, que emplea ecuaciones simultáneas. En este caso, una dedicada a determinar los factores relacionados con la existencia de resultados significativos y la segunda que estudia el impacto en la salud dada una serie de factores. Para obtener después una estimación de la magnitud de este impacto, los efectos marginales globales fueron calculados a continuación.

Los resultados de este capítulo no solo encuentran una relación positiva entre la promoción de espacios verdes y la salud, sino que encuentran evidencia de ciertos fenómenos relevantes como el rol de la renta en la relación. En este caso, los datos corroboran la noción, descrita ya en la literatura analizada, de que las áreas verdes tienen un potencial para reducir la brecha sanitaria entre distintos grupos sociales. Este es un resultado de especial relevancia a la hora de diseñar políticas públicas, debido a ser una externalidad positiva a tener en cuenta al margen del propio beneficio en la salud que pudieran tener las áreas verdes. En general no se encontraron diferencias relevantes entre los tipos de salud tratados, si bien los impactos sobre salud general eran menores que cuando se trataban tipologías específicas. También ofrecían resultados de mayor magnitud aquellos que trataban la mortalidad, debido principalmente a su mayor capacidad de encontrar resultados significativos. Entre las variables demográficas se encontraron efectos limitados a la edad y a la proporción de habitantes residentes en áreas urbanas. Por el contrario, no se encontró un impacto significativo de la variable "género".

La importancia de los factores contextuales en la relación entre áreas verdes y salud es el resultado más relevante de este estudio junto con el propio impacto evaluado en sí. Se trata de una noción intuitiva, pero determinar qué factores son relevantes y en qué medida es necesario a la hora de continuar con el análisis de los impactos de los entornos naturales y seminaturales en la salud y bienestar de las personas. Sin embargo, aún quedan cuestiones pendientes de resolución. La necesidad de ampliar la literatura persiste pese a este tipo de análisis, debido a la variabilidad de metodologías que limita la cantidad de estudios que pueden ser incluidos en tales análisis. Asimismo, debe tenerse en cuenta el potencial sesgo de publicación al que se enfrentan estos tipos de análisis. Otro paso potencial a tomar para avanzar en este ámbito es la valoración de los impactos económicos de estas mejoras en la salud.

Reconceptualizando las estrategias de adaptación urbanas: Visiones de expertos implicados sobre respuestas duras y blandas al cambio climático

(Reconceptualising urban adaptation strategies: stakeholders' insights on hard and soft responses to climate change)

El cambio climático es un contexto al que han de adaptarse de una u otra manera la mayor parte de los estudios relacionados con entornos naturales, y construidos y con las características ambientales. El caso que nos ocupa en este cuarto capítulo está relacionado con los impactos que el cambio climático pueda generar y la adaptación a los mismos. Esta adaptación a los impactos del cambio climático tiene un aspecto marcadamente local, y es por ello que el estudio realizado en este apartado partió de una reunión entre autoridades locales y distintos expertos en la que se expusieron y analizaron las medidas de adaptación mencionadas en las intervenciones realizadas por los participantes invitados a la reunión. Entre las autoridades locales se incluían trabajadores del Ayuntamiento de Bilbao con labores relacionadas con la protección ciudadana y la prevención de riesgos, así como con salud pública. Entre los expertos se incluyó a investigadores expertos en adaptación al cambio climático y en la relación entre éste y la salud humana. La reunión tuvo lugar en el propio consistorio bilbaíno.

El uso de metodologías basadas en discusiones grupales entre expertos y otras formas de interacción entre agentes implicados permite aunar el estudio del tema a tratar a la diseminación de éste. En este caso, permitió a expertos ofrecer sus visiones a las autoridades obteniendo *feedback* sobre las dificultades de implementar algunos de los resultados de sus estudios.

El evento constó para ello de dos sesiones: una primera en la que estos participantes expusieron sus trabajos en torno a impactos del cambio climático, adaptación a éste y salud y bienestar de las personas, durante la cual un miembro del equipo anotó las medidas preventivas y adaptativas que eran mencionadas en las intervenciones. En la segunda sesión, se expusieron a los participantes estas medias extraídas de sus intervenciones, que las valoraron en términos de costes y beneficios a través de una evaluación ordinal.

Estas medidas, un total de 26, fueron luego agrupadas a través de sus características y los beneficios y costes estimados para cada una fueron también agregados para así estimar los costes y beneficios que los expertos asociaban a los distintos tipos de medidas de adaptación al cambio climático. Varias técnicas de *clustering* fueron empleadas a fin de encontrar la que más se ajustara a las características de las medidas propuestas. Finalmente, el método de agrupar elegido fue el coeficiente de similaridad de Ochiai, si bien las discrepancias entre las distintas metodologías eran en diversos casos irrelevantes para el alcance de este estudio. Las medidas fueron ordenadas en seis grupos (una de las medidas fue descartada por su escasa similaridad con el resto) y sus puntuaciones fueron agregadas para su posterior análisis. Dado el limitado número de observaciones y a que el número de estas no era constante a lo largo de los distintos grupos debido al distinto número de medidas incluidas en cada uno, una técnica de *bootstrapping* sirvió de complemento al análisis estadístico. Esta se basó en la extracción de medias aritméticas de las muestras de cada grupo, proceso repetido hasta obtener un total de 10 000 observaciones por cada uno de los grupos que después fueron analizadas estadísticamente.

Los grupos que se crearon permitían segregar entre medidas basadas en infraestructuras grises; medidas preventivas; adaptación y mitigación no basada en ecosistemas; investigación científica centrada en el medio ambiente; adaptación y mitigación basada en ecosistemas; y urbanismo. La observación de estos grupos hizo ver que las medidas de adaptación basadas en infraestructuras "grises" eran percibidas como a la vez más costosas y beneficiosas, mientras que las medidas centradas en los ecosistemas y la investigación científica en estas cuestiones eran valoradas también como muy beneficiosas, si bien la investigación era considerada como menos costosa. Medidas basadas en el urbanismo o en la gestión de la información y prevención de riesgos eran percibidas como menos eficaces a la hora de atajar los impactos del cambio climático.

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Prefacio - Preface

Este trabajo de tesis es fruto del trabajo realizado por el doctorando a varios proyectos internacionales —INHERIT (INter-sectoral Health and Environment Research for InnovaTion); COST Action TObeWELL (Tourism, Wellbeing and Ecosystem Services)— y por tanto ha contado con la colaboración de distintos equipos en varios centros de investigación europeos. Tanto la introducción como las conclusiones (Capítulos 1 y 5) han sido elaborados por el doctorando con motivo expreso de ser incluidos en esta tesis. El proyecto de tesis fue descrito en las II Jornadas de Doctorados en Economía y Empresa de la Universidad del País Vasco UPV/EHU, en el año 2016.

El Capítulo 2: *The nexus between climate change, ecosystem services and human health: Towards a conceptual framework*, fue elaborado por Aline Chiabai, Sonia Quiroga, Pablo Martinez-Juarez, Sahran Higgins, y Tim Taylor. Fue posteriormente publicado en la revista Science of the Total Environment en abril de 2018. La referencia completa del trabajo es:

Chiabai, A., Quiroga, S., Martinez-Juarez, P., Higgins, S., Taylor, T., 2018. The nexus between climate change, ecosystem services and human health: Towards a conceptual framework. Sci. Total Environ. 635, 1191–1204. doi:10.1016/j.scitotenv.2018.03.323

Las contribuciones principales del doctorando en este capítulo incluyeron la búsqueda y clasificación de los artículos incluidos en la revisión de la literatura, la extracción de resultados descrita en la sección 2.3 de esta tesis, una contribución relevante a la elaboración del marco conceptual documentado en la sección 2.4 y a la extracción de conclusiones y resultados del capítulo, además de tareas de redacción en todas las secciones salvo la 2.2.

El Capítulo 3: *Exposure to green areas: Modelling health benefits in a context of study heterogeneity*, fue elaborado por Aline Chiabai, Sonia Quiroga, Pablo Martinez-Juarez, Cristina Suárez, y Tim Taylor. Con variaciones mínimas el texto se encuentra en proceso de entrega para la revista Environment International. El proceso de elaboración de una base de datos fue descrito en una contribución a la European Climate Change Adaptation Conference (ECCA) en el año 2015. Como artículo, fue enviado a la revista *Ecological Economics* y se encuentra en proceso de ser evaluado.

Las contribuciones principales del doctorando en este capítulo incluyeron la revisión de la literatura antes descrita, así como la extracción de datos cuantitativos de ésta para la elaboración de una base de datos que agrupara estos resultados. El doctorando también realizó una contribución parcial al análisis de los datos y de los resultados del propio análisis, incluyendo la extracción de datos utilizados en la modelización y mapeo de los resultados, así como a las conclusiones y la discusión descritas al final del capítulo. Asimismo, el doctorando realizó tareas de redacción en todas las secciones.

El Capítulo 4: *Reconceptualising urban adaptation strategies: stakeholders' insights on hard and soft responses to climate change* fue elaborado por Pablo Martinez-Juarez, Aline Chiabai, Cristina Suarez, y Sonia Quiroga. Como artículo, fue enviado a la revista *Sustainability* y se encuentra en proceso de ser evaluado.

Las contribuciones principales del doctorando en este capítulo se centraron en la selección de modelos de *clustering* y análisis estadístico para la elaboración del estudio además de la realización del mismo. También realizó una contribución significativa a la organización del evento del que partió el estudio, al análisis de los resultados y a la extracción de conclusiones y resultados del capítulo. Además, el doctorando realizó tareas de redacción en todas las secciones.

1. Introduction: The use of economic methodologies in the analysis of health impacts of natural environments

Since the introduction of agriculture, humankind has progressively and in an almost ever-growing manner pushed towards urbanisation. This evolution prompted scholars of every period to analyse of the relation between humans and the natural environment, where health has been a major focus of interest. Yet, it was not until the arrival of the industrial revolution in the 19th century that the mainly romantic views of this relation were overcome and the matter was analysed with proper tools. Rapid and uncontrolled urban migrations set the path towards unhealthy living environments where poverty and pollution started to take a toll over urban populations even at a time where scientific developments pushed upwards the standards of living in contemporary industrialising countries. This process has been reproduced for the last two centuries as more and more regions experienced industrialisation processes and seemingly, will continue in the near future as more countries advance in that same path. The spread of Noncommunicable Diseases —NCDs—, which are behind almost 70% of worldwide deaths (Mendis 2014; WHO 2017), has been associated to these changes in livelihoods. Pollutants found in urban contexts may affect respiratory health, while sedentary lifestyles have potential negative effects over cardiovascular functioning.

Another phenomenon, directly related to industrialisation, that plays a role in the present study is climate change. The expected impacts of climate change will affect human lifestyles and health as well as the relation between humankind and the ecosystem itself. Changing environmental conditions may suppose a direct threat towards health. Different problems will, with different levels of certainty, impact societies all over the world. Increasing temperatures may negatively affect urban liveability by aggravating the Urban Heat Island —UHI— effect, extreme events such as droughts, heatwaves or floods may also cause serious damages, changes in the patterns of vector-borne diseases are also predicted to impact several regions increasing health-related risks. Potential damages span a variety of hazards, in terms of loss of lives, of physiological and psychological damages, loss of material properties and the interruption of services.

Both are issues based on the need to tackle the potential health impacts of changing environments. The possibility of addressing public health issues related with the living environments of an ever-increasing number of people appears to be necessary. Priorities in urban planning have changed throughout the times. Nowadays, the possibility of creating urban landscapes that incorporate health, aesthetic, environmental and economic criteria opens opportunities for improving wellbeing of citizens from various perspectives.

Health problems are both cause and consequence of poverty. Inequalities in health are present at the international level es well as within developed nations. Low and middle income counties present a high concentration of NCD-related mortality and morbidity, which is related on the one hand to a loss of productivity, and on the other to increased costs of preventing and treating such illnesses (Mendis 2014). Within industrialised countries, food consumption habits have been found to be poorer in income-deprived area due to problems of either access or pricing. This phenomenon has led to higher obesity levels in such environments, which are usually correlated with the spread of NCDs.

1.1 Antecedents

The work most commonly mentioned as the key antecedent for this analysis is Roger S. Ulrich's work, where he analysed surgery recovery periods in patients to describe shorter post-surgery recovery periods for those patients with a room with a view of a natural landscape (Ulrich 1984). During the following three decades and up until the present, the literature has spread in terms of methodologies and results, not all of them equally meaningful (Lee and Maheswaran 2010). Several literature reviews have tried to address the issue of covering this span and the resulting heterogeneity (Sandifer et al. 2015; Van den Berg et al. 2015; Martinez-Juarez et al. 2015; Gascon et al. 2016; MacBride-Stewart et al. 2016).

A relevant part of the extension of this work builds on top of specific analyses that try to determine how different types of natural and seminatural environments such as urban parks, gardens or forested alleys affect several aspects of human health. These studies are Thoroughly reviewed in Chapter 2, though several can be highlighted here due to their bearing. Studies like the one performed by Maas et al. (2009), who studied prevalence rates in a wide range of health issues for Dutch populations depending on the surrounding percentage of green space in their living areas. A second study that appeared to be relevant as antecedent was the work by Mitchell and Popham (2008), focusing on the potential diminishing of health inequalities provided by green areas. They observed that, while green spaces were related to lower overall mortality levels, these decreased in a more pronounced fashion in impoverished neighbourhoods. Another group of researchers (Amoly et al. 2014) produced another example of research that was used in both Chapters 2 and 3 of this analysis. Their contribution to the issue was focused on mental health of younger populations, among them ADHD symptoms. On the issues related to elderly population's health, it is possible to find studies like Takano et al.'s (2002), who study the impact of different elements of the urban environment over survival rates, and Hu et al. (2008), who analyse stroke mortality to a different series of environmental characteristics. A common interest of several studies were precisely cardiovascular diseases. An example of the studies analysed in this case is the one performed by Pereira et al. (2012), where coronary heart disease was analysed by studying hospital admissions as well as self-reported cases. Mental health has also drawn attention from several studies. It has been linked for example to vulnerable population's wellbeing in studies such as the one taken by Roe et al. (2013), who studied stress levels in urban vulnerable residents.

This study builds also on the literature describing impacts of climate change and adaptation strategies. Climate change is expected to affect human health in diverse ways. The anticipated changes in both natural and human systems will likely arise through changes in temperatures, the water cycle and sea level rises (IPCC 2014; Smith et al. 2014). Following the compiled impacts and risks described in the last UNFCCC Assessment Report (AR5) (IPCC 2014) several trends can be emphasised. Temperature increases are expected to increase heat-wave related mortality, which the paralleled decrease in cold-wave mortality wouldn't compensate. Increase in temperature is expected to be closely related to the water cycle. While overall precipitation levels are expected to be reduced, causing water scarcity and its related health problems, extreme events are also foreseen to be increased, intensifying the risks of injury and death. Sea level rises may also contribute aggravating the risks of flooding in coastal areas. Changes in temperature and humidity could increase the spread of vector-borne diseases, both in their geographical extent and in the time-dimension. Another issue considered by Smith et al. (2014) is the potential health negative impact of several climate-altering pollutants such as CO_2, which could threaten food safety in coastal areas due to acidification. Similarly, pollutants released in combustion processes, ozone, have been related to millions of life years lost.

Adapting to climate change is therefore a collective need. Also within their contribution to IPCC's AR5, Smith et al. (2014) outlined a series of adaptation measures to be considered. The spread of early warning or early alert systems (EAS) are among them, as well as vulnerability mapping. Co-benefits are also considered within the AR5 and are a key issue in the analysis performed in the present work. Co-benefits, also ancillary benefits in some literature, arise when strategies of actions targeting a specific issue have spillovers into other sectors. Nevertheless, the emphasis of the first lay upon health co-benefits arising from climate change mitigating actions instead of adaptive strategies.

Distribution is another relevant question worth considering in the context of climate change. Regions home to already vulnerable populations have been linked to heavy impacts of climate change. Impacts are expected to affect several stressors affecting vulnerable populations. This is the case of reduced yields, which would affect food security; it could also cause property damages in the case of extreme events, due to increased vulnerability of constructions in such areas; additionally, it could increase conflictivity, leading to an important threat to health and physical integrity. From the adaptive perspective, vulnerable regions often show lower adaptation capacity than developed nations. Displacements of people are one of the available options for adapting, though they suppose by themselves several health threats for those taking the path.

Finally, main antecedents in Chapter 3 are also to be found in the literature proposing participative methodologies. Participatory processes have gained increasing attention in the last decades and have been applied in several research lines in economics, being environmental and development economics two fields where they have proven to be useful resources. Such methodologies have appeared in diverse forms and creating a genealogy of them is well beyond the scope of this study, though early literature reviews may offer an insight over this matter (Chess and Purcell 1999; Lynam et al. 2007). Nevertheless, this work does build on several approaches taken. Such is the case of ecosystem services assessment, where the capacity of locals to identify such services may help researchers in their job (Raymond et al. 2009). Local knowledge may also prove a vital resource in agricultural economics and in order to evaluate impacts of climate change (Quiroga et al. 2015) as well as addressing adaptation (UNFCCC 1992; Few et al. 2007).

1.2 Objectives

This work has several objectives all relating to the potential impacts of natural and seminatural environments over human health and wellbeing and their potential use as Ecosystem-based Adaptation —EbA— in the climate change context. Its first aim, also a first step into the analysis is the study of the existing literature, both scientific and grey in order to identify the main advances and the state-of-the-art findings in the issue. Once a general overview of the subject is obtained, it is also within the aims of this study to develop a working theoretical framework that helps understanding the interrelationships identified throughout the literature modulating the matter of study. Due to the interdisciplinary nature of the questions tackled, this framework should fulfil the task of allowing experts of different sectors to have a common ground for the construction of further analyses. This is not only helpful for the present analysis but should also be a valid resource for future research.

The following objective is to provide a quantitative estimation of the health impacts provided from green spaces over human health and therefore wellbeing. Due to the heterogeneity of the studies targeting this research questions, which differ in methodologies as well as specific health issues or the analysed link between study subjects and green environments, most of metanalyses performed have been constrained to qualitative or descriptive examinations. It has been therefore a difficult task to provide an overall estimation of the impacts described in the literature, which makes it a particularly relevant task to move towards this objective.

Another aim pursued in this work is to obtain the view of different experts from various backgrounds on the issue of potential benefits and costs of Ecosystem-based Adaptation measures as compared with non-EbA soft adaptation, and grey or hard adaptation measures, with the goal of reaching an estimation of their potential efficiency levels. Estimating efficiency is a relevant issue whenever tackling public investment, but the participative approach based on an expert workshop had also the objective of gathering experts of different fields in a collaborative scenario in order to boost intersectoral cooperation.

Finally, the whole of this work has the objective of finding gaps in research. There are still several questions to be solved in the different matters tackled in this work.

Throughout the analyses performed, some of these unanswered questions and fields requiring further research will be identified. The subjects dealt with here have been of research interest for the last decades and it is intuitive to think that will uphold their importance, if this does not grow, during the short term.

1.3 Hypotheses

Two main hypotheses can be identified in this analysis, one related to the effectiveness of natural and seminatural environments in improving human health and wellbeing and the second linked to their efficiency in tackling with climate change impacts and serving as adaptation measures. These two perspectives are analysed in different sections of this work. While Chapters 2 and 3 focus on the effectiveness perspective, Chapter 3 appears as efficiency-oriented.

The first hypothesis is based on the question of whether natural and seminatural environments pose an opportunity for improving health that compensates potential health problems caused by them such as allergies. This hypothesis is based on premises such as the potential of green areas to promote exercise and active lifestyles. Such environments have also the potential to absorb pollutants that could negatively impact respiratory health. From the psychological perspective, it has also been hypothesised that parks have the capacity of reducing stress and strengthen social engagement. It is the hypothesis of this work that these net benefits are countable and positive.

Efficiency is a key issue when trying to search for the optimum public response to climate change impacts. Adapting to climate change often requires vast investments, as require adapting to a wide range of impacts (increased seasonal rainfall, increased temperatures, draughts…) with considerable uncertainties. Often, opportunity costs are also considerable. The hypothesis of this analysis is that soft adaptation measures, and particularly EbA are perceived y experts to be more efficient ways to deal with climate change related impacts.

1.4 Methodologies

To initiate the process a literature review was performed searching both scientific and grey literature. This process has been maintained throughout the study period due to the necessity of keeping an updated record of the existing bibliography, and therefore studies have been added at several stages of the work. Several online databases were searched in order to extract papers. At the point of completing Chapter 2 of this research 117 studies had been gathered. In order to conceptualise the information retrieved, a model was built summarising the main relations identified in the literature reviewing process. Details of the steps followed for the analysis can be found in Chapter 2 section 2.3. An overview of the literature review including references of all works found during this literature review and a basic classification of these works has been included as Appendix A of this work.

Studies gathered during the literature reviewing process were added to a database in order to keep track of them. Furthermore, studies offering quantitative approaches to the issue were differentiated and incorporated to a second database for the following analysis. This process is detailed in Chapter 3, section 2.1, where the chosen studies are also firefly described. an econometric analysis of results was built using the data collected in that database. This data was complemented with international organisations sources (WB, Eurostat, OECD, IMF…) in order to expand the analysis and obtain more precision in the analysis by including contextual variables. A Heckman selection model (Liu and Waite 2014; Hoornbeek et al. 2015) was used in order to analyse in a quantitative manner the results found in the literature. The full process is described in Chapter 3, sections 2.2 to 2.4. Variables chosen are described in section 2.2, while the general methodology on which the Heckman selection model is based is described in section 2.3. The analysis appearing in Chapter 3 is complemented by a simulation of the expected impacts throughout European regions, following Vance's approximation (Vance 2009).

The analysis performed in the third research was not derived from the initial literature review performed. In this case, in order to have an insight on the perceptions of experts a workshop was carried out in Bilbao gathering several professionals in different sectors thaw dealt with issues related to climate change impacts and adaptation (Chess and Purcell 1999; Few et al. 2007). The methodologies here summarised are described in detail in Chapter 4 section 2. The procedures followed as preparation and during the workshop events are described in section 2. Participants were selected among experts in diverse fields and sectors related to climate change, its impacts and adaptation. The workshop included a section where each participant could make a short description of their fields of expertise. Researchers took note of the potential adaptation measures mentioned or implied in these contributions which where, in a second section of the event, ranked by participants. Based on participants' responses and on the nature of the measures included, these proposals were classified following Ochiai's coefficient of similarity (Ochiai 1957). This process appears in Chapter 4, section 2.3. Due to the low amount of data, a bootstrapping technique (Efron 1979; Lahiri 2013) was used to strengthen the analysis (Chapter 4, section 2.4). Finally, based on the classification and on the values given by experts to different measures, an estimation of their perceptions was made.

1.5 Structure of the work

The present work is organised as follows: After the present introduction, Chapter 2 deals with the literature review and its analysis. This includes a section (2.2) dealing with the general interrelation among climate change, green spaces and human health from the ecosystem perspective; a summary of the main findings and several studies drawn from the literature in section 2.3; and the formulation of a framework model based on the findings from the literature review in section 2.4; and the conclusions extracted from the analysis accompanied by a brief discussion in concluding section 2.5.

Chapter 3 uses econometric methodologies to analyse the quantitative results appearing in the literature review made, namely, a hackman selection model complemented by the analysis of the marginal changes predicted by the model. Namely, it explains in section 3.2 the tools and methods employed for the analysis, including the selection of the studies and the variables, the Heckman model included, and the methodology used to calculate marginal effects; results obtained from the various steps of the analysis are presented in section 3.3; and finally, those results are discussed in section 3.4, alongside conclusions extracted from the analysis.

Chapter 4 shows the procedures and results from the workshop and the subsequent analysis of the views that appeared through the event. The methodological process is described in section 4.2, and covers the case study context, a general notion of participatory processes and the concept of perceived efficiency, a description of the clustering technique employed and of the bootstrapping methodology used; section 4.3 presents the results at different stages of the analysis; results that are discussed in section 4.4, which also contains the general conclusions obtained.

Chapter 5 will present the general conclusions as well as a summary of the main conclusions observed from the work. A discussion of the findings is also included in a different section of the chapter. Subsequent topics such as research gaps and further research needed will also be dealt with in this chapter.

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2. The nexus between climate change, ecosystem services and human health: Towards a conceptual framework

2.1 Introduction

Human health and ecosystems' health are inextricably linked. Our understanding of the interconnections between human health and the natural environment has increased rapidly in recent decades. The burden of disease from environmental risk factors is significant – from air pollution and water pollution to the impacts of UV radiation on skin cancer. Unhealthy environments cause just under 1 in 4 deaths globally (Prüss-Ustün et al. 2016). Beyond these proximal pathways to environment and health, recent work has focused attention on the distal pathways – affecting health through impacts on ecosystems (Reis et al. 2015). Contact with nature and ecosystem services (ES) have been shown to contribute to improved immune system functioning, mood and concentration, while reducing stress and increasing the benefits of physical exercise, with consequent expected reductions in the occurrence of non-communicable diseases (NCDs). ES capture all goods and services provided directly or indirectly by the natural environment (Millennium Ecosystem Assessment 2005).

Impacts on health, such as heart disease, diabetes, cancer, and chronic respiratory illnesses, are now a global health epidemic. N36million people died in 2008 from NCDs, and the impact is projected to increase to 44 million by 2020, with higher vulnerability in urban areas and among economically disadvantaged groups (WHO 2011). Health impacts have a direct and indirect effects over the economy. Society can suffer from the loss of working hours and productivity, increases in sanitary costs, as well as intangible impacts (loss of quality of life, discomfort and pain) that should be added to the non-market costs of disease.

The impact of climate change on ecosystems includes a range of impacts that may have an effect on health – from changes in water availability in rivers to changes in biodiversity and vector borne diseases. Green spaces will probably be impacted by climate change in a number of ways – with consequent effects on human health.

Adaptation to climate change is also expected to have an impact on green space provision. There is increasing attention on the role of “nature-based solutions” to respond to the threat of climate change. These solutions will have consequences for human health. Such measures are often classified under the Ecosystem-based Adaptation term EbA) (Vignola et al. 2009). These strategies cover a wide range of actions, aimed at a broad scope of impacts. The use of green spaces in order to increase urban permeability is one of the clear examples. Another frequently mentioned potential benefit is the reduction of the Urban Heat Island effect (or UHI, i.e. the excess temperature caused by urban heat retention) (Doick et al. 2014). Both increased flood risk and augmented temperatures are expected impacts of climate change.

This paper aims to synthesise the existing literature on the nexus between climate change and adaptation, green spaces, and human health and to bring together a conceptual framework to enable the identification of the impacts on health of changes in green spaces as a result of climate change and adaptation measures.

Conceptual frameworks have previously been applied in contexts such as the impact of changes in the water environment on health – and used as a way of identifying potential responses. This is the case of works such as that performed by Gentry-Shields and Bartram (2014), who took the Driving force-Pressure-State-Exposure-Effect- Action (DPSEEA) as the starting point in creating their framework. DPSEEA was designed by the WHO as a framework to develop environment health indicators (Kjellström and Corvalán 1995).

The modified DPSEEA extended this framework to explicitly consider the impact that context has on the environment-health relationship (Morris et al. 2006). A more recent model, the ecosystems-enriched DPSEEA considers the impacts that changes in ecosystems and associated ecosystem services can have on health (Reis et al. 2015). This paper builds on eDPSEEA as a first step towards a holistic perspective on health, climate change and green spaces that will give a better understanding of the factors that influence health outcomes in this context. The resulting framework may facilitate interdisciplinary communication in research in establishing the main aspects influencing the relation between EbA and wellbeing.

The paper is organized as follows. Section 2 discusses the interrelations among climate change, green space and human health by taking a perspective based on ecosystem services, ecological functioning and their potential capabilities. Section 3 takes the health perspective in order to summarise the literature analysing potential impacts of green spaces over human health, with a critical analysis of methods applied, health outcomes analysed and exposure. The importance of contextual variables is also discussed and how they can influence the relationship health-ecosystems. Section 4 presents a framework with key relationships between main elements of the system based on the eDPSEEA model and considering the interplay of contextual variables and types of exposure. Section 5 presents the main conclusions drawn.

2.2 Climate change, green space and human health: the ecosystem perspective

Greenspace, particularly in urban settings, is often viewed as a homogenous 'green area', with little consideration for the biological or ecological components of the landscape. This may be important when particular types and qualities of habitat types have been highlighted as having greater or less influence over the health benefit gained (Alcock et al. 2015; Wheeler et al. 2015). However, pressures on greenspace from both persistent urbanisation and effects of changing climates may also to lead to adverse health impacts (ecosystem disservices) associated with extremes in temperature, vector-borne diseases and water and air quality regulation (McMichael et al. 2006).

Within urban areas, greenspaces may vary significantly in quality (i.e. biodiversity), size and morphology and may have a multifunctional role within an urban area. The health benefits we derive from ecosystems are delivered as a consequence of the biodiversity, ecological composition and processes (Díaz et al. 2006; Cardinale et al. 2012) within the greenspace. The interactions between organisms within their physical environment results in a variety of ecosystem processes (e.g. decomposition), which in turn enables the ecosystem to perform functions (e.g. nitrogen cycling). These ecosystem functions, in turn deliver a number of important ecosystem services (e.g. crops) which support the health and wellbeing of the population (Alfsen et al. 2011).

Perturbations from stressors such as climate change on the ability of the greenspace to perform these functions will likely impact on the delivery of many of these ecosystem services and consequently the health and wellbeing of the local population (McMichael et al. 2006). Climate change will likely impact on the distribution of tree species (e.g. Benito Garzón et al. 2008) and measures may need to be taken in certain green spaces to plant climate resilient species. Extreme events, including droughts and floods, impact on green spaces in different ways. Drought impacts on grassed areas and the hardness of soil underfoot for those exercising in green spaces. Flooding can reduce accessibility to green spaces – though yielding benefits in terms of flood protection through sustainable urban drainage systems, recreational benefits to health may be reduced.

The wider human health vulnerabilities to climate change have been highlighted by a number of key climate change studies (Haines and Patz 2004; Haines et al. 2006; Hajat et al. 2010; Hames and Vardoulakis 2012; Smith et al. 2014; Wolf et al. 2014) and international reporting (Confalonieri et al. 2007; European Environment Agency 2015) and by having a better understanding of how the physical properties of vegetation, water bodies and ecological processes of green spaces (Elmqvist et al. 2015) may actively have a protective effect on health are only just being considered. Harnessing ecological processes and working with natural systems more broadly, can provide a variety of additional co-benefits to both ecosystems and improving public health by enhancing the natural capital rather than depleting it. For example, urban tree planting, plays a key role in mitigating against the impacts of air pollution by retaining particulates and thus improving air quality and improving respiratory related infections/disease, particularly in children (Lovasi et al. 2008).

By 2050 70% of the global population will reside in towns and cities. Continued urbanisation and climate change will interact and exacerbate the health effects of urban heat islands, increased risk of flooding and urban heat islands. In urban settings, greenspaces deliver several key services to adapt to these health impacts. These include, but are not limited to, (i) regulation in microclimates though modifying local temperature regimes so as to reduce the urban heat island (UHI) effect, (ii) acting as a buffer to reduce air and acoustic pollution, (iii) regulate water flow to alleviate flood risk and improve water quality, (iv) promote opportunities for improved wellbeing (Table 2.1).

2.2.1 UHI effects

Some of the most important impacts of climate change are derived from changes in temperatures. Heatwaves are a source of potential losses in terms of health, especially in an urban context and for certain social groups, including ageing population (Day 2008;

Yu et al. 2010; Tobías et al. 2014; Li et al. 2015; Benmarhnia et al. 2016). The Urban Heat Island (UHI) effect refers to the warmer temperatures typically experienced in urban areas compared to the surrounding suburban and rural areas (Heaviside et al. 2017). Changes in land cover and land use through the process of urbanisation can interact with climate change effects and alter local microclimates, consequently the risk of heat related illness or mortality may increase (Vardoulakis et al. 2014; Heaviside et al. 2017). Urban greenspaces have been shown to have lower air temperatures by approximately 1 °C cooler than the surrounding countryside (Bowler et al. 2010). This cooling effect is attributed to shading from broad leaved vegetation, but also from the ecosystem process of evapotranspiration. This process cools leaf surfaces and air temperatures as solar energy is absorbed and stored (Edmondson et al. 2016). Furthermore,

__Table 2.1__: Summary of the key ecosystem services of greenspaces for adapting climate change impacts on health. Key ecosystem processes and functions that contribute to their delivery and example health outcomes.

Biophysical structure/process of greenspace	Ecosystem Function	Ecosystem Service	Example Health Outcome	References
Trees and shrubs mix	Evapotranspiration; solar radiation reflectance; carbon sequestration	Climate regulation: Reduce UHI effect	Reduced urban mortality rates	(Edmondson et al., 2016, Knight et al., 2016, Heaviside et al., 2017)
Trees, mixed vegetation	Leaf wax/hair trap particles on leaf surface Absorption of Co2 for photosynthesis	Waste services: Reduce air pollution	Reduction in cardiovascular and respiratory conditions	(Litschke and Kuttler 2008, Nowak et al. 2014, Weerakkody et al., 2017)
Multi-level vegetation, grass, soil	Water retention by canopy, absorption of precipitation by soil, reduced runoff, drainage	Flood protection: Flood risk alleviation and water quality	Reduction in mental health conditions and economic costs associated with flood exposure; improved water quality	(Bartens et al. 2008, Zellner, et al. 2016)
Biodiverse; pathways; amenity areas	Primary productivity, biodiversity	Recreation: Health and wellbeing of exercise	Opportunities for recreation and physical activity; stress reduction; lower blood pressure, obesity and diabetes	(Mitchell and Popham, 2007, Mitchell and Popham, 2008, Maas et al., 2006, Rook, 2013, Wheeler et al., 2015)

Source: authors

unlike impermeable surfaces such as roads and buildings, leaf surfaces reflect solar radiation back into the atmosphere there by maintaining a lower temperature (Grant et al. 2003). However, these cooling effects are subject to variation owing to the different sizes, shapes and species composition of the greenspaces.

2.2.2 Air pollution

Urban pollution is also another cause of health problems that takes special part in urban ecosystems (Gordian et al. 1996; Pope III et al. 2002). Green areas can help to capture some of the particles that cause health problems, even if it is also suspected that particulate retention may be just temporal. In urban settings, trees have beneficial impacts on the aesthetics of local environments. However, their impact on air pollution regulation is more complex and there is evidence of mixed net effects of trees on health due to air pollution (Salmond et al. 2016).

Trees remove pollution from the air by capturing particulates on the leaf surface. Different species may be more efficient at capturing a variety of particulate matter and increasingly, the evidence suggests that the structural complexity, type and species are all important in maximising the health benefits and indeed, avoiding the dis-services, of maintaining and creating greenspaces. For example, in a wind tunnel experiment, coniferous tree species (Pinus sylvestris) was found to be more efficient at particle capture than broadleaved species (Räsänen et al. 2013). Similarly, vegetation with more complex leaf structures and combinations of species on green walls are likely to maximise particulate retention (Weerakkody et al. 2017). However, understanding species appropriateness (i.e. ecophysiological responses to pollution or heath stress) for the proposed location is a key consideration so as to avoid health dis-services such as respiratory conditions due to low level ozone (O3) formation (Calfapietra et al. 2013; Knight et al. 2016) and/or increases allergic responses to pollen (Escobedo et al. 2011; Cariñanos and Casares-Porcel 2011).

2.2.3. Water regulation

In the UK, climate change will increase heavy rainfall and as a result, risks from fluvial and surface flooding (DEFRA 2016). Greenspaces, particularly urban greenspaces have significant potential to alleviate the risks posed to urban centres. Absorption of rainfall by soil and canopies can play a role in diminishing the hazard of floods (Graceson et al. 2013; Claessens et al. 2014; Warhurst et al. 2014). Reduction of flood impacts could also be obtained through the retention of debris. Green areas can therefore serve as an adaptation measure in a short-term scenario (Opperman et al. 2009), especially in plans involving sustainable flood management and Ecosystem-based Adaptation (EbA) to climate change.

Trees and other broadleaved vegetation intercepts rainfall and slows the transfer to the ground, thus reducing the risk of flooding. Owing to the reduction in excess water, water quality is improved as surface pollutants (e.g. nitrate, phosphates) washed into receiving water bodies are much reduced. Upstream land management of greenspaces for flood prevention has received much recent attention. For example blanket bogs act as natural sponges and retain rainfall to slow its passage downstream (Pilkington 2015). Furthermore, well-functioning wetlands play a big role in water regulation, both on the sides of supplying water and improving its quality. Their capacity to store and treat waters under certain circumstances (such as grey waters and their use as tertiary treatment in wastewater treating procedures) avoids eutrophication of other ecosystems providing therefore a cleaner environment (Millennium Ecosystem Assessment 2005).

2.2.4. Health and wellbeing

Public open green spaces may encourage various forms of interaction among humans, promoting community cohesion, sense of identity, education and learning. Active lifestyle promotion (Giles-Corti et al. 2005; Fan et al. 2011; Almanza et al. 2012; De Jong et al. 2012; Mytton et al. 2012; Gidlow et al. 2016) and the development of social networks (Maas et al. 2009a; Fan et al. 2011; Eriksson and Emmelin 2013; Dadvand et al. 2016), may play an important role as underlying factors in capturing such benefits from green spaces. The relation between health inequalities and the green environment has been also observed, notably by Mitchell and Popham (2008). Mitchell and Popham, based on English data, found a negative relationship between green spaces and health inequalities, which means that deprived socio-economic groups may benefit in greater degree from health benefits of nearby green areas, which would narrow the gap in health issues among income groups. Germann-Chiari and Seeland (2004) found that urban green spaces are not optimally distributed in terms of social cohesion in the case of Swiss cities. Among other aspects analysed in this context the matter of access to parks has also been discussed (Barton and Pretty 2010; Cohen et al. 2013; Carter and Horwitz 2014).

Furthermore, greenspaces play a key role in tourism and recreational activities. An example is given by the Spanish IMSERSO program which promotes social tourism among senior citizens (Hoyo and Valiente 2010). The conjunction between social tourism and ecotourism might bring important health and wellbeing benefits, especially among vulnerable groups (McCabe et al. 2010). Promotion and development of new forms of tourism would have an impact on a region's economy. Evaluation of the economic impacts from green areas go further than the financial benefits of activities related to them, but must take into account all benefits provided. Recreational activities performed in a park, for example, do not necessarily imply market transactions, but have an impact on wellbeing. Methodologies that evaluate these impacts have been developed and discussed in the economic literature, and include approaches that value environmental goods through alternative markets known as revealed preferences (such as the costs of visiting a place or the costs of restoring it after its loss), or stated preferences (such as the willingness to pay of individuals to maintain the good or the willingness to accept a compensation for the loss of the good).

Humans are affected by the contact with different microorganisms. An increasing number of diseases affecting urban populations in developed regions are related to problems in immune-regulation and regulation of inflammatory responses (Rook 2013). The microbiome is present in most of the human body (Proctor 2011), it affects in many cases physiological health, and it does so in different ways (Huffnagle 2010; Bisgaard et al. 2011) through complex interactions (Clemente et al. 2012). There is still much work to be done, as research in human microbiota is restrained by the difficulties of laboratory analyses of most of these organisms (Han et al. 2012). Human physiological responses to aseptic environments, most easily achieved in urban contexts, could block the set of processes that are triggered by these commensal organisms, among them the development of tolerance to some of the organisms themselves, case that generates some of the most common health problems in the developed world according to the WHO[1]. According to the text of Rook (2013), exposure to natural environments and green spaces, along with the microecosystems, would help the correct development of human immune system. There are, of course, also potential risks from exposure to certain microorganisms, for example the potential for infection, including antibiotic resistant bacteria (Wellington et al. 2013).

2.3. Green spaces and wellbeing: the health perspective

Green spaces have diverse impacts on human health and wellbeing, and this is reflected in the diversity of the studies performed in the exploration of the relationships between ecosystems and health in this context. Human health is highly dependent on the environment. It has been postulated since early times (Ward Thompson 2011) that being surrounded by nature improves human wellbeing. With the arrival of the industrial revolution the impact of pollution became more relevant for public health (Ward Thompson 2011), so that the role of urban green areas can be key in this context. The links between natural environments and improved health are well documented (Maas et al. 2006; Alcock et al. 2015; Shanahan et al. 2015a, b; Triguero-Mas et al. 2015), however. the mechanisms remain elusive. Evidence suggests that access to and availability of urban green and blue spaces provide a wealth of opportunities for health promotion, such as reductions in stress, anxiety and depression, reductions in diabetes, and cardiovascular and respiratory disease through an increase in opportunities for physical activity (Hartig et al. 2014; Shanahan et al. 2016).

We performed a search through web resources such as Web of Knowledge and Google Scholar combining terms related to the areas of environment and health. A series of combinations including health related terms (health, disease, life expectancy, mortality, epidemiology, etc.), environment-related words (environment, nature, ecosystem, pollution, green spaces/areas, etc.) were used. Complementary terms (such as qualitative, statistical, literature review, etc.) were introduced when necessary. Snowballing from the literature, particularly literature reviews, was another source of references. We included previous literature reviews and meta-analysis looking at

[1] http://www.who.int/chp/en/

quantitative health impacts, qualitative studies using empirical data from surveys looking at subjective perceptions, and finally a number of studies offering theoretical approaches and discussions to analyse the interaction. In total 117 studies were identified that investigated these relationships.

The whole reference list of the reviewed studies is displayed in Appendix A (Supplementary Data), including a table (A) which classifies all studies by methodology and health outcome(s).

***Table 2.2**: Summary of articles describing impacts of green spaces over health.*

Study type	Reference and location	Health outcome	Exposure	Main Contribution	Res
Objective	(Maas et al. 2009b) Netherlands	Persistence of disease (grouped in clusters).	Presence of green space in residential area.	To assess whether physician-based morbidity outcomes are related to green space in living environments.	Rec clu rac lim
	(Takano et al. 2002) Tokyo (JP)	Five-year survival rate.	Range of neighbourhood characteristics, including green items.	To find the relation between public areas' greenery in residential environments and elderly populations' longevity in densely populated urban contexts.	Spa line rela sig
	(Hu et al. 2008) Escambia and Santa Rosa counties (US)	Stroke mortality.	Greenness and pollutants measured through GIS.	To determine the relation between stroke mortality and a series of factors (air pollution, income and greenness).	Sig rec
	(Mitchell and Popham 2008) England (GB)	General health and on cardiovascular disease (CVD) among other factors.	Statistical area classification according to percentage of greenspace.	To test whether health inequalities correlated with income would be less pronounced in populations more exposed to greenery.	Sig for cor
	(Pampalon et al. 2006) Québec (CA)	Different health aspects, including life expectancy and different cause mortality.	Census areas according to their urbanization level.	To compare the health contexts of rural and urban areas in Québec.	Imp Hea
	(Cusack et al. 2017) Texas (US)	Preterm births, small for gestational age cases and term birth weights were taken as birth outcome measures.	Normalized Difference Vegetation Index (NDVI).	To study birth outcomes with respect to residential greenness in the Texan context.	Ter res mc hig
	(Hanski et al. 2012) Eastern Finland	Atopic sensitization/allergic disposition was analysed in a sample of adolescents.	Surrounding biodiversity in residence area.	To provide evidence to the "biodiversity hypothesis", which would imply that reduced contact with environmental features is related to the increase in prevalence of certain illnesses.	A r bio low
	(Henke and Petropoulos 2013) Wales (GB)	Measures of limiting long term illnesses, mortality, physical activity guidelines met and life expectancy were taken into account.	Recreational areas in Wales were identified and their extension measured as proportion of each local authority.	To explore the interconnections among ecosystem services, human health and deprivation in a context where green ecosystems are abundant.	Lov rela exp
	(Huynen et al. 2004) Not local	A series of indicators were employed: (disability adjusted) life expectancy, infant	Different indicators were used to calculate biodiversity loss: percentage of	To address the potential relation between biodiversity loss and health at a global scale.	Sig for pro bio

		mortality and percentage low-birthweight babies.	threatened species, changes in forest cover and the percentage of land highly disturbed by man.		
	(Tamosiunas et al. 2014) Kaunas (LT)	Both CVD-related deaths and non-fatal cases were accounted from a population cohort.	GIS data on parks larger than 1ha were taken. Use of parks was also considered.	To study the interrelations between distance and sue of green areas on the one hand and prevalence of CVD and its risk factors on the other.	He stu dis
Subjective	(Van Herzele and De Vries 2012) Ghent (BE)	Self-reported health and well-being.	Two neighbourhoods were selected similar in all terms except the availability of green spaces.	To study the connection between local environment's greenness and health and wellbeing of those living in such environment.	No
	(Dunstan et al. 2013) South Wales (GB)	Self-reported general health	Three tertiles were constructed through the Residential Environment Assesment Tool (REAT), which includes environmental elements	To investigate the relation of health with residential environment's quality taking an objective measure of the latter.	No nat
	(De Vries et al., 2003) Netherlands	Survey based on diagnostic interviews for mental health assessment, focusing on anxiety disorders, mood disorders, substance abuse and common mental disorders (CMD).	Presence of green space in residential area.	To address the question of whether greener areas' populations are healthier by studying self-reported health of Dutch populations in combination with land use data.	The of p dis
	(De Jong et al. 2012) Scania (SE)	Three measures of wellbeing, all of them self-reported: Neighbourhood satisfaction (NS), physical activity (PA) and general health (GH).	Scania Green Score (SGS): Index based on perceived green neighbourhood qualities, "culture", "serene", "lush", "spacious" and "wild"; as well as perception over each of the components. GIS-based objective greenness was also a measure taken.	To implement the SGS index in the context of analysing health and wellbeing of Scanian population.	Wh sep me act also last inc sim exc and
	(Mansor et al. 2012) Taiping (MY)	Questions on the relation between green space and wellbeing were included in the questionnaire.	Combination of a questionnaire survey and semi-structured interview on urban green areas of the city chosen.	To study the attitudes of citizens with respect to green infrastructure in relation with wellbeing.	Gre infl on per
Proxy	(Grazuleviciene et al. 2015) Kaunas (LT)	Systolic and diastolic blood pressures (SBP; DBP), heart rate (HR) and recovery, and exercise duration were measured at different points.	Two randomised patient groups exposed to different walking settings: urban and green. All of them were exposed to 30-minute walks during a 7-day period.	To assess whether walking in a green environment has an increased effect over coronary artery disease.	Eff per gre

	(McKenzie et al. 2013) Scotland (GB)	Medication prescriptions as a proxy for mental health.	Urban and rural classification of neighbourhoods.	To analyse the potential association between living environments and mental health problems such as anxiety, depression and psychosis.	Urb pre
	(Witten et al. 2008) New Zealand	Body Mass Index and measures of activity.	Car travelling times as proxy measure for distance between neighbourhoods and parks and beaches	To tackle the question of whether access to public space can lead to increased levels of physical activity.	No of t BM
	(Grazuleviciene et al. 2014) Kaunas (LT)	Pregnant women were classified into four blood pressure categories (optimal -baseline-, normal, high-normal blood pressure, and hypertension). ORs were calculated for the relation among these and greenness groups.	Subjects were classified among three groups according to distance between residence and the nearest park. Apart from this discrete measure, continuous distance was also used.	To analyse the effect of distance to urban parks over blood pressure categories during the early stages of pregnancy.	On ind gro cor clo wh cas dim
	(Li et al. 2011) Tokyo (JP)	Blood and urine measurements were taken before and after the activity. Blood pressure was analysed at various points during the study (three times during the activity day and the morning after).	Two randomised subject groups (all healthy male) exposed to different settings: urban and green. They spent a day within the assigned environment, walking for 2 hours in the morning and afternoon.	To study the effects of walking in forests over cardiovascular and metabolic indicators of male subjects.	Blo nor sig day and on hig
Combined subjective and objective measurements	(Min et al. 2017) South Korea	Depression was assessed with a question referring to the immediate 12-month period, while depressive symptoms were addressed through a standardised questionnaire. Suicidal intention was addressed through two questions.	Extension of parks and green areas in each residential geographical code along South Korea.	To scale the research on the potential benefits of parks and green spaces over mental health from the local to the national level.	Ind pre pre tha
	(Pereira et al. 2012) Perth (AU)	Coronary heart disease (CHD) and stroke based on self-reported cases and analysis of records of hospitalizations.	NDVI	To investigate in a specific manner the greenness of a neighbourhood in relation to CHD.	Ove dec and fou
Combined subjective and proxy measurements	(Ward Thompson et al. 2012) Dundee (GB)	Cortisol levels and self-reported stress and well-being measures in individuals in vulnerable situation	Percentage of green zone over the total area of the neighbourhood.	To study health benefits of green areas using "ecologically valid objective measures" and to determine whether salivary cortisol may be used as a biomarker in the research of stress levels.	No of c wit

(Yang et al. 2011) Zhejiang (CN)	Brainwave activity, complemented by a questionnaire	Visual stimuli of areas with different degree of greenness	To address the psychological side of noise reduction provided by plants.	Ade in g
(Roe et al. 2013) Dundee (GB)	Salivary cortisol and perceived stress were measured in jobless men and women between 35-55 years residing in deprived districts of the city. Wellbeing was measured through a shortened version of the Warwick and Edinburgh Mental Well-being Scale (SWEMWBS).	Green space measured according to percentage of green spaces in the Census Area Statistics.	To analyse the mechanisms operating under the relation between the environment and mental health, particularly in the context of stress in jobless populations.	Pos slo hig wa The fou sig per wa

Source: authors.

The diversity of the literature with quantifiable results span throughout three main axes which we can classify as: broad methodological approach, heath outcome and exposure. In Table 2.2 we present a selection of the reviewed 117 studies with quantifiable results, classified by the three categories above. Methodological approaches used in the literature were classified into three groups (Martinez-Juarez et al. 2015). Namely we distinguished among "objective studies" (using objective measurements of health), "subjective studies" (relying on subjective or survey-based measurements) and "proxy measure based studies" (relying on proxies that can be precursors of health problems). In the next three sub-sections we discuss some key studies identified in each of the three groups, commenting the specific methodology used and main results obtained. Based on the analysis of the 117 studies we subsequently propose different types of exposure characterising the type of individual involvement with nature, and finally present a discussion on the role of contextual factors in the interaction health environment.

2.3.1. Objective studies

Objective studies use different types of health data such as hospital admissions for specific health conditions, changes in life expectancy or mortality, all of which could be measured in an objective manner using risk factors and statistical metrics. Studies of this type include epidemiological studies such as the one performed by Maas et al. (2009b). The authors analysed one-year persistence rate of illnesses aggregated in 24 clusters in order to study the effect of greener living environments on health. Positive impacts were found in most of the health clusters for greener areas located closer living environments (1 km radius), while effects diminished when more distant areas were taken (3 km). Mental health impacts were most notable. According to their results, green spaces impacted anxiety in a higher degree, with a decreased odds ratio (OR) of 0.95, while depression exhibited a reduction in persistence associated with an OR of 0.96. Both results were significant at the 95% significance level. Other illnesses with significant decreased ORs were coronary heart disease (0.97 odds ratio), several musculoskeletal complaints, such as back and neck complaints (with OR diminishing to 0.98), asthma, COPD and upper respiratory tract infection (OR of 0.97), neurological disorders (ORs between 0.97 and 0.98), and digestive infectious disease of the intestinal canal (OR 0.97).

A different approach was taken by Takano et al. (2002), who analysed changes in survival rates in the city of Tokyo, and found that environmental aspects such as the presence of space for taking a stroll, streets with parks and trees near the residence areas were associated with higher survival rates. This study found that spaces for taking a stroll could significantly increase survival rates both for males and females. For example, parks and trees were positively related to overall survival rates, showing an increase from66.2% to 74.2%when parks and trees increased from a minimum amount (defined qualitatively as "very little") to a maximum (defined as "plenty"). The relationship was, however, not always significant when analysing specific subgroups of the population (e.g. females).

While also objective, a somehow different approach was taken by Hu et al. (2008), who analysed stroke mortality in two US counties and also found evidence linking greener environments to improved health conditions. Their specificity in the approach lies in the proposed model which uses a combination of mapping with Bayesian hierarchical modelling combined with Monte Carlo analysis. The resulting figures showed that greenness presented a mean effect of−0.161, with a credible set spanning from −0.289, to −0.031, which implies a significant reduction of stroke mortality in greener areas. Air pollution also had relevant effects, though of the opposite sign.

Mitchell and Popham (2008) also considered mortality rates in their study, though their finding was that not only green spaces could have a positive impact over health, but that this impact could be stronger in groups with lower income levels, having thus an reduction effect over health inequalities. Incidence rate ratios (IRR) varied among groups. For all-cause mortality, IRR between most and least deprived areas in least green areas was of 1.93, while in the greenest areas IRR was reduced to 1.43. Circulatory disease mortality showed a change from 2.19 to 1.54 under same circumstances.

Another study considering mortality we wish to highlight was performed by Pampalon et al. (2006). The study was centred over the differences in health between urban and rural areas. Mortality in rural areas was found to be significantly higher, compared to urban areas. The study also emphasised the importance of contextual factors in this relationship. In this study, improved health in urban areas resulting from improved access to healthcare puts a limit over the greener-is-better relation.

2.3.2. Subjective studies

A second group of studies use self-reported measures of health, which we named “subjective studies”. Health questionnaires are used in order to obtain measures of general health as well as to tackle specific health problems as anxiety or cardiovascular health. Likert scales are often used in this type of studies in order to facilitate respondents in reporting their perceived health status. Semi-structured interviews and Yes/No question sets or inquiring over the number of symptoms remembered over a time period can also help in analysing population's

health. Although self-reported measures exhibit a number of biases, they can ease the task of addressing health in a subjective way. These methods are often combined with different measurement metrics such as proxy indicators which can detect a health problem. Such mixed analyses are included in the third group of studies and described later.

Van Herzele and De Vries (2012), used a questionnaire in order to ask for the health status of inhabitants of two neighbourhoods in Ghent, one being substantially greener than the other, while other characteristics being similar. Inquiry over self-reported health used a 1–7 Likert scale to ask for general health and added a question over the number of symptoms experienced by individuals. The study found no significant improvement in self-reported symptoms, but it did find higher levels on reported general wellbeing in the greener neighbourhood. A different questionnaire was used by de Vries et al. (2003) when conducting their research on the relationship between greenspace and health. They examined the amount of green in the study subjects' living environments and found a positive relation between greener environments and self-reported health. The latter was measured combining a five-point Likert scale for perceived general health combined with an inquire to recall symptoms in the last 14 days. In this case, a version of the General Health Questionnaire was used to determine propensity of participants to psychiatric morbidity. De Jong et al. (2012) used self-reported levels of physical activity as well as perceived green qualities in their study, finding a positive association among these variables. In their analysis of a series of neighbourhoods in South Wales, Dunstan et al. (2013) studied reported levels of poor health and objectively measured neighbourhood quality. REAT (Residential Environment Assessment Tool) serves as index for neighbourhood quality, and is comprised by a series of 28 items encompassing aspects such as physical nuisance and incivility, territorial functioning, defensible space, natural elements and miscellaneous other factors. Natural elements (green spaces and infrastructures) had however no significant impact over health in this analysis.

2.3.3. Proxy measure based-studies

The third type of studies are those relying on proxy measures. These proxy measures can be intended as a precursor to disease and health status, so they are particularly relevant to detect health benefits from exposure before the disease can manifest. This is the case of cholesterol measures, cortisol presence, prescription of medications, Body Mass Index (BMI), etc. Some of the studies using such variables combine them with other measurement types such as perceived health from survey-based analysis. We include here examples of the use of proxy measures and of combined systems.

Yang et al. (2011) studied brainwave activity through electroencephalogram (EEG) in order to assess psychological noise reduction gained when using landscape plants as buffering system. The study involved visually and stimulating participants with either green images or images showing traffic elements while noise stimulation was also applied. A control group was also employed as reference. The study relied too on subjective measurements provided by participants. These last measurements showed that there was a widespread belief that landscape plants had an impact over noise reduction, 90% of respondents believed so, with an 80% of participants considering them the most efficient option. Participants tended to overrate the noise reduction capacity of plants measured, with 55% of them overstating the capacity, 40% giving accurate values and 5% underestimating the effect. Significant variations were found un beta-1 and beta-2 waves between those subjected to green stimulation, and traffic and control groups. Variations in alpha-1 and alpha-2 waves were restricted to a couple of brain areas. No significant changes in delta and theta waves was found. They found an additional reduction caused by the use of these elements.

McKenzie et al. (2013) used drug prescription levels in order to analyse mental health in different settings in Scotland, finding that urban settings were more prone to the use of prescription drugs targeting depression and anxiety. Blood pressure is another common measure in studies. Such are the cases of two studies performed in Lithuania

(Grazuleviciene et al. 2014, 2015). Both studies found improvements in their measuring in groups more influenced by parks and green areas. In the 2015 study, researchers tested whether coronary artery disease (CAD) patients' hemodynamic parameters would show more positive effects after park walks than after urban strolls. Systolic (SBP) and diastolic (DBP) blood pressures as well as heart rate (HR) were analysed at rest, after exercise (differences after 1 and 30 min) and after a 7-day exercise period. Effects appeared for all variables after the week. The second study analysed blood pressure in the early pregnancy. Participants were classified into four groups, ranging from optimal (blood pressure) to hypertension. In order to measure exposure to ecosystems distance of residence to a park was used, both continuous and discrete (b300 m, 300–1000 m, N1000 m). OR were calculated by comparing odds of being classified in a higher-blood pressure group according to proximity of residence to an urban park. OR adjusted to risk factors indicated increased OR for intermediate groups with respect to the baseline group (optimal) when comparing lower distance group with those living closest. Increase was also significant when analysing distance continuously. For the case of the hypertense group increased OR diminished and lost statistical significance.

Similarly, Li et al. (2011) took measurements of participants' blood pressure after walks in different contexts (a walk in a forest park and an urban walk). These measurements were combined with urine samples which were used to calculate noradrenaline and dopamine levels. Evaluation of the proxy variables led researchers to determine a positive effect of walking in greener contexts. Among those that employed different proxy measures we can find Witten et al. (2008), who combined BMI, sedentary behaviour and physical activity levels. The aim of the study was to analyse the impact of access to public open space over those variables. In order to determine access to parks and beaches, minutes of travel by car were used as variable via GIS. They found access to parks not linked to reduced BMI or sedentary behaviours, though they found a correlation when studying access to beaches.

Ward Thompson et al. (2012) took a combined approach when analysing stress in deprived communities. They used salivary cortisol as their main measure for stress, complementing it with a self-reported measure. Salivary cortisol was measured at different points during the day. Between 3 and 12 h after the awakening time. Greenness and deprivation measure were based on participants' postal areas. Self-reported stress was found to be correlated to greenness. Steeper cortisol evolving patterns (higher in the early hours after awakening and lower after 12 h) were correlated to wellbeing, physical activity and greenness, as well as with improved self-reported stress. Mean levels of cortisol were not associated to greenness or lower levels of stress. These relations were significant at the 95% level.

2.3.4. Type of exposure

How exposure to green areas is conceived is another source of variance in the literature. Following the previous proposal of classifying exposure to green spaces into active, consumptive and passive exposures (Martinez-Juarez et al. 2015b), we comment hereby some studies from the literature based on this classification. The relevance of this classification

lies on the importance of the engagement with green areas and its effect over the analysed relation. Several of the positive (and negative) health impacts of green areas over human health is associated to either active, consumptive or passive forms of engagement or exposure.

Active exposure requires involvement of the subject. This type of connection can include actions such as taking a stroll in a park (Takano et al. 2002; Roe and Aspinall 2011), social interactions in green public open space (Maas et al. 2009a; Wood et al. 2010; Eriksson and Emmelin 2013; Fleming et al. 2016) or exercising in green areas such as an urban forest (Scully et al. 1998; Kerr et al. 2006; Hansmann et al. 2007). The study performed by Lachowycz and Jones (2014) tested the hypothesis that walking explained lower mortality levels appearing in areas with higher access to green space. They found that inhabitants of greener neighbourhoods were between 13% (when taking neighbourhood green space) and 18% (when considering green space within a 5 km radius) more prone to engage in recreational walking in the last 30 days.

We classify as consumptive means of exposure those interactions with nature that involve consuming some of its products or services. Though ecosystem services provide health benefits through consumptive exposure (e.g. the provision of medicines and the regulation of products such as clean water that are consumed by individuals allowing them for healthier lifestyles), these services are not common in small green areas. A case for increased health through consumptive exposure to green areas is green tourism.

The mere presence of green areas may also have an impact over health, whether or not individuals actively interact with them, case which we classified as passive exposure. Green areas can provide health benefits reducing air pollution (Sæbø et al. 2012); by regulating climate, particularly reducing the UHI effect (Bowler et al. 2010); or by creating a suitable environment for the developing of healthier microbiotic conditions (Hanski et al. 2012; Rook 2013; Rook et al. 2013).

2.3.5. The role of contextual factors

Certain issues appear throughout the literature and have an important role modulating the interrelationships between the ecosystem and health. We consider these as contextual variables which can have different roles and degrees of importance, but must be considered in order for health impacts to be appropriately measured. Demography is an important factor that can influence ecosystem's impacts over health. Population density, ageing, health status are some examples. There is a direct relation between population density and pollution that could imply higher benefits in health. This would be due to the increased marginal impact of green spaces in a more polluted environment. On the contrary, congestion of parks and green spaces could deter people from using parks or reduce the restorative effects of park visitation. Age has been another factor considered. Ageing populations could benefit from clean air and open space to walk and engage in social activities. Takano et al. (2002) deal with diverse demographic aspects by focusing the research on elderly populations in a densely populated environment and providing gender-specific results. Socioeconomic questions such as income (Mitchell and Popham 2008) or joblessness (Ward Thompson et al. 2012, 2014; Roe et al. 2013) have also been considered in the literature. Social aspects may also influence attitudes towards green spaces influencing the relation, such as time spent in open space or use of such areas to perform physical activity (Wright Wendel et al. 2011). Studies can handle these variables in different ways. Some studies overlook them entirely, whereas others consider them as control variables. Age, gender and socioeconomic conditions are central in several studies. We therefore consider them as a key aspect in the construction of the conceptual framework as discussed more deeply in the next section.

2.4. The conceptual framework based on eDPSEEA

We propose a framework which draws on the "ecosystems enriched" Driver, Pressure, State, Exposure, Effect, Action (eDPSEEA) model (Reis et al. 2015) and explicitly integrates climate change and potential cobenefits that green areas could provide in terms of adaptation actions through population exposure and contextual factors. Ignoring such benefits would conduct to sub-optimal planning and decision-making (Fig. 2.1). For this purpose, the eDPSEEA model has been adapted to specifically link impacts of climate change and adaptation action on the environment and how this can affect human health through different types of exposure.

Findings from the literature reported in the previous sections and taking into account both the ecosystem (Section 2) and health perspectives (Section 3), were analysed in order to create a framework that could incorporate cause-effect interactions among climate, ecosystem services, exposure and health impacts in a schematic and synthetic manner.

The "driver" in our model is climate change and includes basically GHG emissions and concentrations which put a "pressure" on green spaces in terms of increased temperature and precipitation patterns, heat and air pollution as well as extreme weather events. The pressure will lead to a potential change in the amount/size or quality of that space (the "state"), producing alterations in terms of ecosystem functioning which will in turn affect the terrestrial distribution of natural areas as well as the flow of ecosystem services they provide in the short and long run. The state has been characterised in our framework by six types of ecosystem services (as discussed in Section 2), which can affect the use or perception of the site through "exposure": UHI effect, air pollution, water regulation, social environment, recreation and tourism, and microbiome.

Depending on a range of contextual factors, which may include socio-economic characteristics of the impacted group (e.g. incomes, ages equity), health status (e.g. obesity), culture, attitudes and beliefs, and environmental factors (e.g. baseline climate, availability of alternative sites), these changes may impact on health either directly or indirectly, positively or negatively (the “effect”).

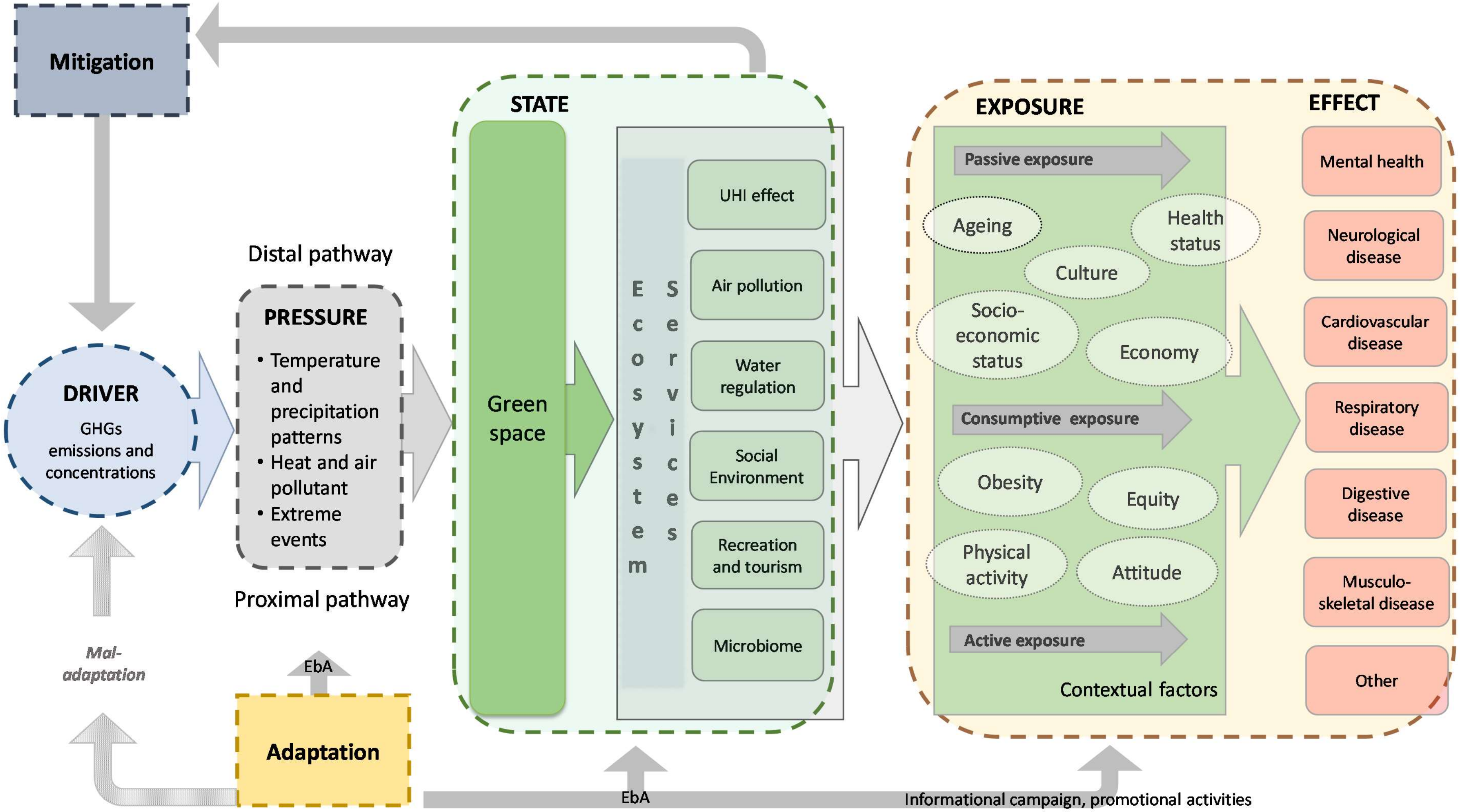

Figure 2.1: *Climate change, ecosystem services and human health: A conceptual framework.*

"Actions" refer here to any intervention affecting green spaces and population exposure, which can impact ultimately on human health. In this context, adaptation will play a crucial role as it could increase the existing pressure on natural areas ("mal-adaptation") or, on the contrary, reduce it with appropriate solutions such as those based on ecosystem-based adaptation (EbA). EbA interventions will show both direct benefits in terms of positive impacts on the provision and quality of ecosystem services, as well as additional co-benefits in terms of population health due to exposure to an improved state of the ecosystem.

In terms of adaptation, both "hard" and "soft" options exist to respond to increased temperatures, precipitation and extreme events. Hard paths for adaptation may have significant impacts on the quality of the natural environment, while requiring inflexible and capital-intensive technologies and the use of non-renewable resources. On the other side, the creation or safeguard of green areas is regarded as a "soft" measure, but it may also help to avoid some of the negative impacts of hard-adaptation measures. An example would be the development of sustainable water management and flood control systems by creating green areas along waterways.

An overview of some key adaptation options, their possible impacts on the natural environment and associated health implications is given in Table 2.3 below. It is important that the assessment of adaptation options takes into account all risks and co-benefits, as otherwise suboptimal policy may result. Health benefits may not be the primary reason for adaptation — e.g. in the case of sustainable urban drainage systems (SUDS) reduction in material damage from flood risk may be the major target, but appropriate design of adaptation should take into account the health benefits as well (Ellis et al., 2004). In the case of flood avoidance, a path may be constructed at the same time as the defence is built to ensure that direct benefits arising from the structure can be complemented by co-benefits such as those arising from active leisure such as walking.

In our framework we include also other actions linked with EbA, which have a direct effect on people exposure and health. These are for example promotional and educational activities fostering responsiveness of individuals to improvements in the state or promoting recreational and physical activities among general population and vulnerable sub-groups.

Impacts on health (the "effect") have been grouped according to the different definitions and dimensions analysed by the literature (Section 3). Specifically for the construction of this framework, we have classified health impacts based on the same seven clusters as Maas et al. (2009b). This allows us to specify how different sets of cobenefits affect human health and wellbeing through diverse aspects of health. The cleaning of the atmosphere from particulate matter and gases such as SO_2 or NO_X (provided by green areas) can, for example, affect health through the reduction of respiratory diseases and probability of developing cancer (Ohshima and Bartsch 1994).

It must be noted that various species of plants may also have a negative impact on health, as they can trigger allergies through their pollination process. On the other hand, there have been studies that link the visit to parks to a reduction of migraines (Hansmann et al. 2007), which would be related to the provision of recreational use of ecosystems. A straightforward cause of improvement would be the reduction in stress. Other effects may be regarded as ambiguous. As plants can also spread allergens while they retain contaminants, the microbiome may have both good and bad effects over human health. The presence of microorganisms can cause a wide range of effects on human wellbeing, from immunoregulatory functions (Rook 2013) to bacterial caused diseases. Immuno-regulation and allergy would have important effects on respiratory illnesses (Huffnagle 2010; Rook 2013), while microorganism-caused diseases affect many physiological functions, though not all the interactions could be related to the presence of ecosystems (Clemente et al. 2012; Han et al. 2012).

Contextual variables, as mentioned in Section 3.5, may be important, including factors of socioeconomic status of the impacted demography, the age profile of the population, the baseline climate and existing levels of health issues including obesity. Contextual variables can affect the relation addressed in various ways according to how subjects are exposed to them. Age, climate and general health conditions, for example, affect all types of exposures – as different age groups may have different responses, climatic conditions may affect recreational uses or perceived amenity and the health of the individual may affect use and the impact that exposure has on health. Obesity has a clear link with consumption, though cultural context is also related to consumption patterns. Finally, active lifestyles and socioeconomic status require an active engagement on behalf of the individual. Some of the studies have paid special attention to the effects of green areas on the health of deprived communities (Mitchell and Popham 2008; Ward Thompson et al. 2012).

The role of these aspects may vary considerably. While ageing can have a negative effect on health through increased risks of some illnesses such as mental health or cardiovascular diseases, obesity may affect gastric and respiratory functions as well as the cardiovascular system. Active lifestyle can by itself generate improvements in a wide range of health aspects, but will also reduce the negative impacts related with ageing and obesity, though it can have both positive and negative impacts over the musculoskeletal system. Ageing, in any case, can be a factor generating a decrease in physical activity. These aspects are related to green areas through different links. Active lifestyles can be considered a product of cultural ecosystem services, as it has been theorized that aesthetically appealing environments may enhance the performance of different activities (Richardson et al. 2013). The level of involvement on active lifestyles can also be affected by air quality, as contaminants may dissuade individuals from involving in physical activity. The positive effect on health of senior citizens provided by the fact of having a place for a stroll near their residence (Takano et al. 2002) can be also regarded as an ecosystem service. Finally, the social involvement may also play a role on the impacts of ageing on human wellbeing, as active communication and preference of life in the same community are related to survival rates among the elderly (Takano et al. 2002).

Table 2.3: *Ecosystem-based adaptation and impacts on the natural environment: some examples.*

Measure	**Possible impacts on natural environment**	**Potential health implication**	**Related bibliography**
Sustainable urban drainage systems	Potential for green corridors for recreation	Possible increase in recreational walking and cycling, improved physical and psychological health	(Ellis et al. 2004)
Green roofs	Potential improvement in views, potential increase in biodiversity	Reduction of pollutants and UHI effect	(Rowe 2011; Santamouris 2014)
Flood defences	Potential to provide paths for walking	Possible increase in recreational walking and cycling, improved physical and psychological health	(Mansor et al. 2012)
Structural measures implanted in wetlands	Increased coverage of wetlands and biodiversity benefits	Possible increase in recreation	(Opperman et al. 2009)
Urban forests	Increased coverage of forests in urban area, cooling and biodiversity benefits	Reduced heat stress and potential for increase in recreational walking and cycling, improved physical and psychological health	(Tyrväinen et al. 2014)

Source: authors.

All these aspects have been labelled as contextual factors, as changes from baseline levels affect health outcomes. Social, economic and demographic characteristics not only influence health, but also affect the way in which green space interacts with it. The evolution of demographics, as explained previously through the case of ageing population, may require a special focus. This may particularly be true for vulnerable socioeconomic groups, such as ageing populations and poorer groups, among others (Maas et al. 2009a; Finlay et al. 2015).

Finally, following Martinez-Juarez et al. (2015a, b), and as introduced in Section 3.4, exposure is considered in the framework in terms of active, consumptive and passive. As previously defined, active exposure is dependent on the activities of the individual and may involve the use of green spaces, for example, to walk or exercise. Apart from physical activities, social activities may also be related to active modes of exposure. In the analysis of the framework, a key role is plaid by attitudes and beliefs of people in this context, which is strictly linked with peoples' empowerment having the purpose of personal growth. Consumptive exposure refers to the consumption of certain elements produced or regulated by the natural ecosystem. Clean water consumption and extraction of pharmacological products from the ecosystems can be mentioned in this sense. Finally, passive exposure (when active engagement is not required and potential benefits come from the sole presence of green spaces, and climate regulation) is a form of involvement in which the nature can improve health by its mere presence. This classification is an added value to the eDPSEEA model and it can help in identifying different types of values linked with exposure, such as recreational or passive use values, which are evaluated using different types of methods in the economic literature (based on stated or revealed preferences).

2.5. Conclusions

The interlinkages between climate change, ecosystems and health need to be properly understood in order to better plan adaptive responses and to ensure potential health co-benefits can be taken into consideration in the design of adaptation measures, particularly where nature-based solutions are being proposed. To date, promising evidence of links between human health and green areas has been found. This evidence was the basis to develop a conceptual framework, which we constructed on the basis of the eDPSEEA framework, with the intent of showing the pathways by which green areas interact with human health. The eDPSEEA-based framework that we propose could help in the development of improved empirical analysis, for example by serving as multidisciplinary platform for discussion among experts and stakeholders. It could also help to identify which relations are more or less covered in the literature and to identify key indicators (both qualitative and quantitative) in each cause-effect relation among elements in the system. This analysis would support future research in providing a basis for operationalising quantitative assessment and modelling health impacts from green areas using statistical approaches.

When analysing the literature, it becomes clear that some aspects have been more thoroughly analysed than others. The implications of this are that some evidence is not uniformly distributed across the framework, which leads to another core for future research. The literature review on the relation between climate, green spaces and ecological functioning from an ecosystem services perspective showed a well-documented association. However, when looking at the specific health impacts from exposure to green spaces (with a health-based perspective), evidence is mixed and not always clear. Even if most of the papers show some degree of correlation between health improvement and the environmental aspect analysed, positive and significant effects are not found in all the aspects examined. The diversity of methodologies and metrics used for measuring exposure and health outcomes, makes it difficult to compare studies and implies an added difficulty in obtaining results that are adequate to be generalised through a quantitative meta analysis. Giving some uniformity in order to allow for a statistical analysis of the data described in the literature is another task requiring further research.

Another important point is the role of contextual variables which are rarely put into focus in the specific literature using the health-based perspective, and when they have been, this has been done in an exclusive way, not taking into account interacting variables. Similarly, research is still needed on how variables such as physical activity, that could be positively correlated with both green spaces and health, may affect the overall relationship. The role of external aspects such as ageing, active lifestyle and diet, has been another major point of the present findings. These factors, that have themselves a big impact on health, should be related to the study of the impact of natural ecosystems on health. They are often risk factors in the appearance of NCDs, such as the case of sedentary lifestyles or eating habits. This implies that analysis of the health impacts of green spaces should incorporate these risk factors in the most comprehensive manner, while the analysis of the literature has shown that this is often a gap. As discussed in the framework, role and implications of these contextual variables is a key issue with a need for further research. Finally, the differing types of exposure considered in this analysis have not either been intensively researched. In our study we made an attempt to classify existing studies according to the type of exposure (passive, consumptive or active), but future research is needed to assess quantitatively the health benefits according to the type of exposure.

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3. Exposure to green areas: Modelling health benefits in a context of study heterogeneity

3.1 Introduction and background

One of the trends constantly present during most of recorded history has been the increase in the population living in cities. Urbanization is a process that has also accompanied industrialization all over the world. In such context, lack of contact with the natural environment is a growing concern (Antrop, 2004; Chen et al., 2008; Wright Wendel, 2011; Wright Wendel et al., 2012). Nature has been identified as an important factor influencing human health. Among the potential benefits that nature offers to individuals, improved health may be put among the most important and a growing body of literature reflects this (Gascon et al., 2016; Lee and Maheswaran, 2010; Lovell et al., 2014).

The relationship between natural and semi-natural environments on the one hand, and human health and wellbeing on the other, has been considered not only by the scientific community but also by entities in charge of promoting health and protecting the environment. The World Health Organization (WHO) accounts for various environmental aspects among the main determinants of health (World Health Organization, 1986). The interactions between environment and health are complex. Environmental factors pose serious risks to human health, as it is estimated that 24% of the global burden of disease is attributable to environmental hazards (WHO, 2006), including air and water quality, land use and urban design. Contacts with healthy environments are therefore central for promoting a better health in the population. This is even more important in the current trend characterised by an increase of non-communicable diseases (NCDs) (e.g. cardiovascular and respiratory diseases, diabetes, cancer) which, according to the WHO, will generate a cost of more than 11 billion US$ to the world economy during the 2011-2025 period (Mendis, 2014). Projections indicate a rise from 36 million deaths due to NCDs in 2008 to 44 million by 2020 globally, especially in urban areas and among poorer groups (WHO, 2011). Prevention of these diseases can be achieved through improved accessibility to healthy environments and promotion of healthier lifestyles (e.g. physical outdoor activity, recreational activities in rural areas and green spaces, etc). Green areas can play a key role in this context, while providing also other benefits such as reducing health inequalities, improving urban biodiversity and contributing to adaptation to climate change (Chiabai et al, 2018).

Different approaches have been taken in order to explain the interactions environment-human health and the associated benefits (Martinez-Juarez et al., 2015). For example, trees can help mitigate risks from air pollution by retaining contaminants present in the urban atmosphere (Nowak et al., 2006), both chemical and acoustic (Stansfeld and Matheson, 2003). Exposure to green environments also interacts with the human microbiome, which can lead to effects on the incidence of inflammatory diseases such as allergies (Rook, 2013; Rook et al., 2013). Among other things, green areas can reduce surface runoff, hence contributing to reduced risks derived from flooding in urban areas. Water cycle regulation provided by wetlands and other ecosystems have important impacts on water supply and water quality. Socioeconomic determinants have also been considered by some authors among the factors mediating in the relation between environment and health. Parks and other open green spaces may promote social cohesion by providing meeting and leisure areas, which may have positive impacts over mental health. The implications for social and economic welfare go beyond this mediating effect. The health burden is particularly strong for income deprived populations. Vulnerable populations are more prone to poor health, and this relationship extends to various aspects of health (Aschan-Leygonie et al., 2013; Mendis, 2014; Mitchell and Popham, 2008; Roe et al., 2013; Ward Thompson et al., 2014, 2012). Health inequalities may lead to poverty traps (Whitehead et al., 2001), with worse health conditions often being accompanied by low incomes. Worse eating habits, lower accessibility to health care, stress and many other causes may lay behind this situation, but improved access to green areas is among the possible mechanisms that have been proposed to reduce these aggravated impacts (Ward Thompson et al., 2014). Urban green areas provide public open spaces that help vulnerable segments of society to access to active leisure or benefit of cleaner air, as well as to improve social links. This may lead to a potential higher health improvement in deprived populations, hence contributing to health inequalities and the associated poverty trap (Mitchell and Popham, 2008). Socio-economic factors can therefore be seen as contextual variables contributing through different pathways to the expected health benefits of improved environments.

In this context, making a comprehensive review of the existing literature is a complicated task. This is due to various reasons. The first is the fact that number of studies relating exposure to natural and semi-natural environments and heath is still growing. Due to critical importance of the issue, this field has attracted many investigators from different backgrounds. This leads to the second challenge, the heterogeneity of methodologies and underlying assumptions. Methodological heterogeneity occurs at different points of the research, such as the variable measurement (e.g. health outcome, exposure), the population selection, the inclusion of contextual factors, and the analytical tools employed. Issues of comparability among studies and the use of different measures of health and green space complicate the identification of the underlying dose-response relationships. This leads to uncertainty as to the “true” relationship between green spaces and health. While there is a seemingly positive relation explored along the literature, the presence of non-significant and negative correlations has led some authors into questioning the validity of any generalization (Lee and Maheswaran, 2010).

Against this background, we aim to explore new approaches to deal with the existing study heterogeneity, in order to extract generalizable conclusions from the literature linking green spaces and human health (Martinez-Juarez et al., 2015). This is a crucial step to facilitate knowledge transfer from academics to civil society on the importance of green space. The hope is that it will also inform better interdisciplinary research in a field where various disciplines may interact.

More specifically, the objective of this paper is to test the use of the Heckman selection model, as a way of identifying the factors influencing the significance of the relationship throughout existing studies and calculating the marginal effects of selected factors found to be crucial. A literature review has been conducted for this purpose, including studies with quantitative results on the health benefits associated with green areas, and a database has been constructed with all relevant variables believed to influence this relationship.

The paper is organized as follows. Section 3.2 presents the methodological approach, including the process of constructing the database with data obtained from the literature and external sources (subsection 3.2.1), the definition of the variables and standardization process (section 3.2.2), the Heckman selection model and its application to the current study (subsection 3.2.3), and the marginal effects associated (subsection 3.2.4). Results are shown in section 3.3, starting with the descriptive statistics (section 3.3.1) and following with the results of the analysis (section 3.3.2), while section 3.4 presents a discussion of these results and the key conclusions.

3.2 Methods

3.2.1 Selection of previous case studies and database

A literature review was conducted including peer reviewed publications on the health benefits provided by green spaces, using a worldwide geographical coverage. A systematic search was done through ScienceDirect and Web of Knowledge, using a set of selected keywords related to natural environment, green areas, ecosystem, ecosystem services, health, mental health, non-communicable diseases, epidemiology, cardiovascular and respiratory diseases. A detailed analysis of the outcomes and approaches was also conducted in order to incorporate the information into a common dataset which was used afterwards for the econometric analysis.

The scope of the literature review was to include studies providing quantitative measurements of the relationship green areas-human health, taking into account a variety of approaches and measures of the health outcome as well as of exposure. This was necessary in order to gather a sufficient number of data, which resulted in a database characterized by a high level of methodological heterogeneity.

Table 1 reports the studies included in the database in terms study location, methods, health outcomes and indicators, as well as the number of observations in total and those with significant results. Each study presents several research cases with individualizable results that we consider as observations in our database¬¬¬ — composed of 12 studies with a total of 184 observations, of which 117 find a significant relationship between health and exposure to green areas at the 95% of confidence interval.

Table 3.1: *Studies included in the database.*

Study	Location	Method	Health outcomes	Observations		Health indicator	Green exposure indicator
				Total	Significant effects		
Maas et al. 2009	Netherlands	Multilevel logistic regression analyses	24 outcomes*	58	26 (44.8%)	Annual prevalence rate	Percentage of green space in a radius of 1 and 3 km around the postal code of respondent's home
Maas et al.,2006	Netherlands	Multilevel logistic regression analyses	Perceived general health	6	6 (100%)	Percent of responses (5-point Likert scale – very poor to very good)	Percentage of green space in a radius of 1 and 3 km around the postal code of respondent's home
Takano et al. 2002	Tokyo, Japan	Multiple logistic regression analysis	All-cause mortality	21	8 (38.1%)	Five-year survival rate for the elderly	Presence of walkable green spaces near the residence (parks and tree lined streets) measured with qualitative indicators
Mitchell and Popham 2008	England	Binomial regression model	All-cause mortality, circulatory diseases and cancer	15	9 (60%)	Mortality incidence rate	Population classified into 5 exposure groups based on the proportion of green space of residence
Pereira et al. 2012	Perth, Australia	Logistic regression	Coronary heart disease	4	1 (25%)	Hospital admissions and self-reported medically diagnosed cases	Neighbourhood greenness for a 1600 m service area around residence using remote sensing data
White et al. 2013	England	Fixed effect regression	Perceived general and mental health	12	10 (83.3%)	Percent of responses (5-point Likert scale – poor to excellent)	Distance to the coast (0–5km; 5–50km; >50 km) and percentage of green space
Dunstan et al. 2013	South Wales	Multilevel logistic regression model.	Perceived general health	3	2 (66.7%)	Percent of responses (3-point Likert scale – not good-fairly good-good)	Neighbour measure of natural environment through Residential Environment Assessment Tool (REAT)
Tamosiunas et al. 2014	Kaunas, Lithuania	Multivariate Cox proportional hazards regression	Cardiovascular disease, fatal and non-fatal	21	21 (100%)	Age-adjusted prevalence (%)	Distance to city parks larger than 1 hectare, categories classified based on spatial land cover data
Poudyal et al. 2009	USA	Life expectancy production function	Life expectancy at birth	18	18 (100%)	Average life expectancy at birth for county residents	Dummy indicating whether the county contains a recreation park, proximity to national park, outdoor attractions, and golf courses per thousand
Pretty et al. 2005	Colchester, UK	One-way ANOVA test	Perceived mental health (depression and anxiety)	4	3 (75%)	Percent of responses (5-point Likert scale –not at all to extremely)	Exposure to visual stimuli (rural and urban photographic scenes)
Roe et al. 2013	Dundee, UK	Multiple linear regression	Perceived mental health (stress)	4	2 (50%)	Perceived stress score (5-point Likert scale –never to very often)	Percentage of green space (parks, woodlands, scrub and other)

Amoly et al. 2014	Barcelona, Spain	Quasi-Poisson mixed-effect model	Mental health in school children	18	11 (61.1%)	Scores for attention deficit/hyperactivity disorder	Proximity to green spaces defined as living within 300 meters of a major green space (≥ 0.05 km2)

Note * = cardiovascular, respiratory, musculoskeletal, digestive, mental, neurological, miscellaneous.

The literature was found to be quite diverse with respect to many aspects, notably the methodological approach, the definition and measurement of the health outcome and the indicator used for exposure, which leads to significant statistical heterogeneity. As shown in Table 3.1, results are mixed with significance varying considerably by study and type of health outcome, suggesting that there is no unique and clear evidence of the impact produced by green environment on human health. We briefly discuss hereby the main issues related to the diversity of the studies reviewed, and in a second step how the data from the literature have been standardized to construct a database for the econometric analysis (section 3.2.2).

The first point to highlight is the variety of methods and statistical techniques used in the literature to analyse the relationship health-green environment, depending on the type of data available, the purpose of the analysis and the health outcome analysed (for a discussion see Chiabai et al, 2018). The studies reviewed can be categorized in two main groups, “objective” and “subjective” studies. The first use health indicators computed with objective measures drawn from health registries (mortality rate, prevalence/incidence of specific diseases, hospitalization rate, life expectancy). The second rely on subjective measures such as opinions and individual perceptions on health status, quantified in survey-based questionnaires with qualitative measures using the Likert scale technique (e.g. “very poor” to “very good”). Both types of measures were used in the econometric analysis based on the recognition that they are equally important in defining the relationship between exposure and individual health status. Indeed people’s perceptions on their health might support and complement the existing objective health statistics, hence it is important to capture the impact of exposure to green space using both types of indicators.

Defining exposure to green areas is another major issue when it comes to analysing their effects on health. The studies in the literature review generally refer to availability of green spaces within a certain distance from people’s living environment and use different metrics for this purpose (e.g. spatial land cover data, Normalized Differences Vegetation Index – NDVI). Accessibility and actual use of green spaces are not contemplated in this analysis, first because of data scarcity, and second because it would ideally represent a subsequent analysis to the current one. Accessibility is associated with a number of factors such as promotional activities, provision of footpaths and exercise facilities, appropriate lighting, enhanced aesthetics and mixed land-use, while it can be hindered by factors such as low path connectivity and heavy traffic.

3.2.2 Variables in the model and standardization process

Given the diversity of indicators used for the two main variables, health outcome and exposure, some assumptions for standardization are needed to carry out the analysis under a common measurement framework. Our first order of business was therefore to create standardized indicators for a common measure allowing for comparison among the results in terms of (i) health risk reduction (HHR) and (ii) exposure to green areas.

In the reviewed studies, the HRR in mortality refers to objective indicators such as mortality incidence rate, five years' survival rate, life expectancy, measured from estimated coefficients in epidemiological functions. The HRR in morbidity may refer either to objective indicators (e.g. annual prevalence/incidence of diseases, hospital admissions) or subjective indicators (e.g. general health perception measured on Likert scale). These indexes were transformed into a standardized percent variation rate referring to different outcomes. In order to differentiate the impacts, several dummy variables were constructed, discriminating among (a) mortality and morbidity effects, (b) objective and subjective studies, and (c) type of health outcome. For the latter we used a classification into five categories: mental health, cardiovascular diseases, respiratory diseases, other health impacts not included in previous categories (musculoskeletal, neurological, digestive, diabetes, cancer), and a universal category "all-cause" or "general health", the latter being used in the literature as a comprehensive classification to refer the general individual health status.

As regards exposure to green areas, the indicators used in the selected studies may refer to the distance of the respondents' home to the nearest park, or percentage of green spaces in the surroundings of respondents' living environment, or normalized difference vegetation index (NDVI) in the living environment which identifies if a target space contains green vegetation or not. In order to create a common indicator for exposure, we constructed three intervals based on the cumulative distribution function of the indicators used in the reviewed studies, which allowed us to build a new metrics with three levels of exposure (low, medium and high). We considered the lowest level of exposure in each study as the baseline, respect to which the change in the health outcome was calculated. The second tercile group of the distribution represented a medium exposure, while the third tercile group represented a high exposure. The baseline acts as reference, and refers to those groups of individuals who are less exposed, if at all, to green areas. The indicator proposed for exposure in the Heckman model is therefore defined as availability of green spaces in terms of size of the area and distance from the people's living environment.

The database constructed for the modelling includes a number of demographic and socio-economic variables as control factors. Most of them were available in the studies reviewed, while others were taken from secondary sources. The full set of variables included in the database is presented in Table 3.2.

Table 3.2: *Description of variables.*

Variable	Description	Data source	Units
Health risk reduction	% change in the health indicator due to an increase in exposure respect to a baseline defined as low exposure.	Selected studies	% change
Mortality	Mortality versus morbidity impact. It allows measuring the differential effect between mortality and morbidity.	Selected studies	Dummy variable (1 for mortality, 0 morbidity)
Subjectiveness	If the study relies on self-stated health, the observation is regarded as subjective, otherwise not.	Selected studies	Dummy variable (1 for the subjective studies, 0 otherwise)
Health outcome	Disease clusters: general (all-cause, general health), mental, cardiovascular, respiratory, others (diabetes, cancer, etc.).	Selected studies	Dummy variable (1 for the selected cluster, 0 otherwise)
Exposure to green areas	Availability of green spaces in the surroundings of people's living environment, measured in terms of vicinity and/or % or density of green.	Selected studies	Dummy variable (1 for low, 2 for medium and 3 for low)
Gender	Proportion of female population over the total.	Selected studies	Percentage (of female on total)
Age	Age groups: young <16, adults 16 to 65, elderly >65.	Selected studies	Percentage (of population in each age group)
Income per capita	GDP/ population for country.	IMF (http://www.imf.org/external/pubs/ft/weo)	GDP per capita
Education	Literacy rate, youth total (% of people ages 15-24).	World Bank (http://data.worldbank.org/indicator)	Percentage
Hospital beds	Hospital bed density (by country).	CIA library (https://www.cia.gov/library/publications)	Number hospital beds per 1,000 people
Urban	% people living in urban areas in each country.	World Bank (http://data.worldbank.org/indicator)	Percentage

3.2.3 The Heckman Model

Though most of the studies reviewed support the idea that green areas can have beneficial effects on human health, this relationship is influenced by multiple factors (environmental, socio-demographic and economic) and is therefore characterized by high levels of complexity and uncertainty. Indeed, many of the studies found in the review show non-significant results, which suggests unclear evidence for health benefits from green areas at the current stage. In such cases, considering only the studies providing significant results would lead to a censured sample and in that case the parameter estimates would be inconsistent and biased. In this context of uncertainty, we tested the Heckman selection model as a way to deal with the unobserved selection factors and correct for the bias in estimating the outcome equation. To our knowledge, this is the first attempt exploring the use of such a model to find out which variables affect the significance of the coefficient under analysis.

If we want to study and make inferences about the determinants on health risks of a population we need to consider the systematic differences between the type of studies which find significant and not significant effects. In this case the analysis is faced by a problem of identification and selection. Selected samples suffer from selection on unobservable because the errors that determine whether a case is missing are correlated with the errors that determine the outcome.

Our objective is to systematize all information available in the literature about the relationship health and green areas, in order to allow the transfer of knowledge in other contexts.

The Heckman selection model is usually expressed in terms of latent variable models and relies on two equations, an outcome equation which includes factors affecting the outcome variable, and a selection equation which considers the part of the sample which is observed and the factors influencing the selection process.

In our case, the outcome equation relates the health risk reduction associated with availability of green areas with a set of explanatory variables such as exposure level, income per capita, type of disease and so on.

In its general form, the outcome equation *Ri* can be expressed as:

$$Eq. 3.1 \qquad R_i = X_i\beta + \varepsilon_i$$

where $X_i$are the explanatory variables determining the health risk reductionR_i; $\beta$is a vector of parameters to be estimated; and ε_i is the error term. In our analysis:

$$Eq. 3.2 \qquad R_i = \beta_0 + \beta_1 mort_i + \beta_2 sub_i + \beta_3 car_i + \beta_4 resp_i + \beta_5 men_i + \beta_6 gen_i + \beta_7 exp_{m,i} + \beta_8 exp_{h,i} + \beta_9 fem_i + \beta_{10} old_i + \beta_{11} adult_i + \beta_{12} inc_i + \beta_{13} bed_i + \varepsilon_i$$

where $mort_i$ is a dummy variable when mortality is measured in study i; sub_i is a dummy variable indicating if the observation is a subjective health perception derived from surveys; car_i is the dummy variable for cardiovascular diseases, $resp_i$ for respiratory diseases, men_i for mental health and neurologic diseases, and gen_i for other diseases (digestive, muscular, etc.); exp_m and exp_h are the exposure levels, medium and high respectively; fem_i is the proportion of females in each observation; old_i and $adult_i$ denote the proportion of population over 65 and between 14 and 65 respectively; inc_i is the income per capita expressed in 2005 USD; and bed_i is the number of hospital beds in the country per 1,000 inhabitants.

The selection equation is the probability that the health risk reduction due to exposure is significant (probability of significance being observed, S_i), which can be expressed as,

$$Eq. 3.3 \qquad S_i^* = Z_i\alpha + v_i$$

where Z_i are the explanatory variables; α is a vector of parameters to be estimated; and v_i is the error term. Equation 3.1 is observed if $S_i = 1$, meaning that S_i^* shows significant effects on risk reduction from exposure, and $S_i = 0$ otherwise.

In our analysis the selection equation takes the following form:

$$Eq. 3.4 \qquad S_i^* = \alpha_0 + \alpha_1 mort_i + \alpha_2 sub_i + \alpha_3 urb_i + \alpha_4 inc_i + \alpha_5 edu_i + v_i$$

Where urb_i is the percentage people living in urban areas and edu_i is the percentage of alphabetized adults in the country.

This is the latent variable model. If S_i^* shows significant effects of exposure on risk reduction then the observed latent function equals to 1, otherwise Ri = 0. The regression equation observes the value of Ri if $S_i = 1$. ε_i and v_i are the error terms of the two equations which are distributed according to a bivariate normal with mean zero, $\varepsilon_i \sim N(0, \sigma_\varepsilon^2), v_i \sim N(0,1)$ and covariance $\rho = Corr(\varepsilon_i, v_i)$. The error terms are independent of both sets of explanatory variables. The model allows for correlation between unobservable information of the two equations. As it is well known, if ρ = 0, the standard regression model applied to equation 1 provides consistent and asymptotically efficient estimators for all model parameters. When ρ≠0, the standard regression model applied to equation 1 provides biased results, while the Heckman model with sample selection provides consistent and asymptotically efficient estimators for all model parameters.

The application of Heckman model in our context allows differentiating among those factors affecting the significance of exposure on the health risk reduction and find out which are the key variables in this relationship.

3.2.4 Marginal effects within the Heckman model

For estimating the model coefficients, we used the full information maximum likelihood estimation method. The estimation involves forming the joint distribution of the two random variables $[\varepsilon_i, v_i]$ and then maximizing the full log-likelihood function. Then the marginal risk reduction induced by the model determinants has been calculated on the basis of the estimated model considering the non-linear effects and for the mean values in the quantitative variables and the median values in the qualitative ones.

The interpretation of the results from the model requires the transformation of the coefficients obtained in order to avoid selectivity bias. Vance (2009) proposes marginal effects and significance testing following the equation:

$$Eq\ 3.5. \qquad \frac{\partial E(R_i | S_i^* > 0, X)}{\partial X_{ki}} = \beta_k - \alpha_k \rho \sigma_\varepsilon \delta_i(-Z\alpha)$$

where the inverse of the Mills ratio is denoted as $\delta(-Z\alpha)$.

3.3 Results of the model

3.3.1 Descriptive statistics

Table 3.3 shows the mean values and standard deviations of the created latent variable health risk reduction and its determinants. The first two columns refer to the whole sample created from the results extracted from the literature review. Average values were taken for numeric variables and proportions in the case of dummy variables. The last two columns analyse the subsection created by selecting just those observations coming from significant results reported in the reviewed studies. The two variables HRR and exposure are measured with the standardized indicators as defined in section 3.2.2. Overall, socioeconomic variables do not show great differences between the total sample and the subsample. However, for HRR and exposure to green areas the difference between the two samples are higher which explains the use of the Heckman selection model.

Table 3.3: *Descriptive statistics of principal variables.*

Variable	Total sample		Subsample (significant effects on health risk reduction)	
	Mean	Std. Dev	Mean	Std. Dev
Health risk reduction	0.848	1.799	1.755	2.263
Mortality	0.297	.458	0.398	0.492
Subjectiveness	0.247	0.433	0.295	0.495
Exposure to green areas				
• High	0.297	.458	0.34	.477
• Medium	0.445	.498	0.307	.464
• Low	0.26		0.35	
Disease type				
• Cardiovascular	0.220	.415	0.08	.272
• Respiratory	0.044	.206	0.045	.209
• Mental	0.198	.399	0.216	.414
• General	0.324	.469	0.477	.502
• Others	0.214	.411	0.182	.388
Urban	81.128	6.458	82.447	4.103
Hospital beds	6.131	3.993	5.476	3.79
Age				
• Young	14.285	7.854	14.28	8.638
• Adults	59.724	26.489	60.72	27.511
• Elder	25.991	31.236	25.0	31.731
Gender (female)	51.966	17.226	48.673	14.448
Education	99.139	0.259	99.05	0.154
Income per capita	29,842.61	10,815.74	30994.29	8190.77

3.3.1 Transfer knowledge: A systematized function for health risk reduction as a response to green areas exposure

Table 3.4 shows the results of the Heckman Selection model separately for each equation. The outcome equation (Ri) explains the health risk reduction associated with exposure to green areas with a set of explanatory variables identifying different determinants (linked to individual socio-demographic factors as well as access to health care in the study region). The selection equation, on the other hand, reveals the determinants affecting the probability of finding significant results in the risk reduction estimated in the reviewed studies. These determinants include variables characterising the study (if focusing on mortality impacts, or on subjective health indicators) and socio-economic factors in the region under analysis (income per capita, percent of people living in urban areas, and percent of alphabetized young people in age 15-24).

The results arising from the selection equation show that the probability of seeing significant results in the health risk reduction from exposure to green areas is significantly higher in studies conducted in urbanized regions, with lower income per capita and literacy rate, as well as in those studies looking at mortality outcome and subjective health indicators.

__Table 3.4:__ Heckman Selection model results.

Independent variables	Outcome equation (R_i): Health Risk Reduction			Selection equation (S_i): Probability that HRR significant		
Mortality	0.5716	(0.897)		1.7911	(0.435)	***
Subjectiveness	-0.0523	(0.849)		1.1635	(0.334)	***
Cardiovascular diseases	-0.0875	(0.388)				
Respiratory diseases	-0.0309	(0.282)				
Mental health	0.3941	(0.579)				
General health	-1.7318	(0.672)	***			
Medium exposure	2.5682	(0.367)	***			
High exposure	3.4530	(0.591)	***			
Female	0.0051	(0.016)				
Elderly	0.0593	(0.035)	*			
Adults	0.0599	(0.038)	*			
log GDP per capita	-2.1062	(1.310)	*	-0.8408	(0.473)	*
log hospital beds per capita	2.6754	(0.715)	***			
Urban				0.0793	(0.028)	***
Education				-1.3205	(0.615)	**
Constant	13.0054	(12.947)		132.1250	(62.209)	**
Wald test of indep. eqns. (rho = 0): chi2(1) 3.27 *						

Note 1: Figures are the estimated coefficients of the model and figures in brackets are standard errors.
Note 2: GDP and beds per capita have been transformed into log to consider the non-linearity effects.
** p < .1; ** p < .05; *** p < .01*

As it can be seen in Table 3.4, the Wald test shows that the covariance between errors in the two equations is significantly different from zero, so that the two equations have to be jointly estimated.

In order to assess the magnitude of health risk reduction and its determinants, however, we need to look at equation 3.5 which estimates the marginal effects (Section 3.2.4) from the system of equations. Equation 3.5 measures the marginal values for the health risk reduction as a response to changes in the determinants—dy/dx for quantitative variables and discrete change of dummy variables from 0 to 1 (Table 3.2). Results are reported in Figure 1 and show that changes from baseline to medium exposure levels are expected to generate reductions in health risks of about 2.6% on average in the study population. This impact increases to a 3.5% for high exposure levels compared to the baseline, though diminishing returns to scale can be intuited from the data, consistent with the literature (Pampalon et al., 2006). This implies that, all values held constant at the average, policies that increase contact with natural or semi-natural spaces may generate health benefits up to 3.5% risk reduction.

Higher risk reductions are estimated for mortality compared to morbidity (+1.4%). As regards the type of illnesses, mental health has the largest impact on risk reduction (+0.39%) compared with the category "other diseases" (encompassing many diseases, such as cancer, diabetes, etc). Though the coefficient is not significant, it shows a tendency of the importance of green areas on mental health in the current context where mental disorders are strongly contributing to the world disease burden (Barton and Rogerson 2017). The broad and comprehensive category "general health" shows lower risk reductions (-1.7%) compared to "other diseases" addressing specific health conditions from exposure to green areas.

As for the demographic variables, gender does not affect significantly the impact, while adults and old people are those gaining slightly more from increased exposure to green spaces, compared to young people (15 years old or less), though the magnitude of the effect is small.

Socio-economic variables have also an impact on risk reductions. Literacy rate, which is used as proxy for education, and income per capita were found to be moderators of the improvement in health. Higher income per capita and higher literacy rate are associated with lower risk reduction associated with exposure to green areas (respectively -1.7% and -0.61%). This is in line with studies found in the literature such as Mitchell and Popham's (2008). From a different methodological approach, other authors such as Wright Wendel et al (2012) or Germann-Chiari and Seeland (2004) have also considered the role of access to green space in low-income groups and areas. On the contrary, health risk reductions are expected to be higher in countries with higher access to healthcare (measured as number of hospital beds per 1,000 inhabitants in the country) (+2.7%) and in more urbanised regions (+0.37%) as expected.

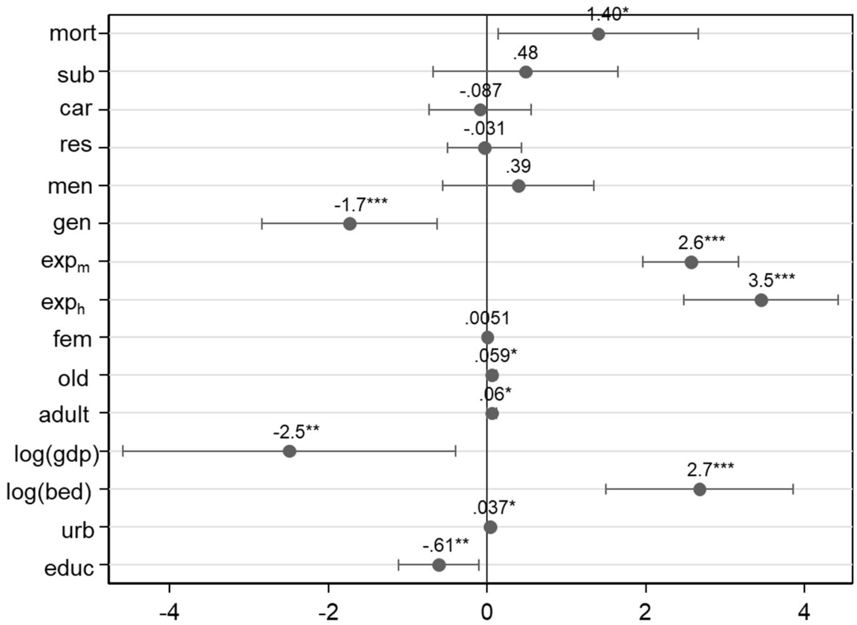

Figure 3.1: *Marginal effects for the Heckman model. Note: marginal effects calculated on the basis of the estimated model considering the non-linear effects and for mean values of quantitative variables and median values of dummy variables. Mortality (mort), Subjectiveness (sub), Cardiovascular diseases (car), respiratory diseases (res), mental health (men), general health (gen), medium exposure (expm), high exposure (exph), female (fem), elderly (old), adults (adult), log GDP per capita (log(gdp)), log hospital beds per capita (log(bed)), urban (urb), education (educ).*

Figure 3.2 shows a simulation of expected HRR using OECD GDP per capita. As it can be seen, the potential for risk reduction is weaker for higher income. The literature suggests that, while impacting positively all or most groups, living nearby green areas can improve health more in income deprived areas (Mitchell and Popham, 2008), thus having a redistributive effect in terms of health equity

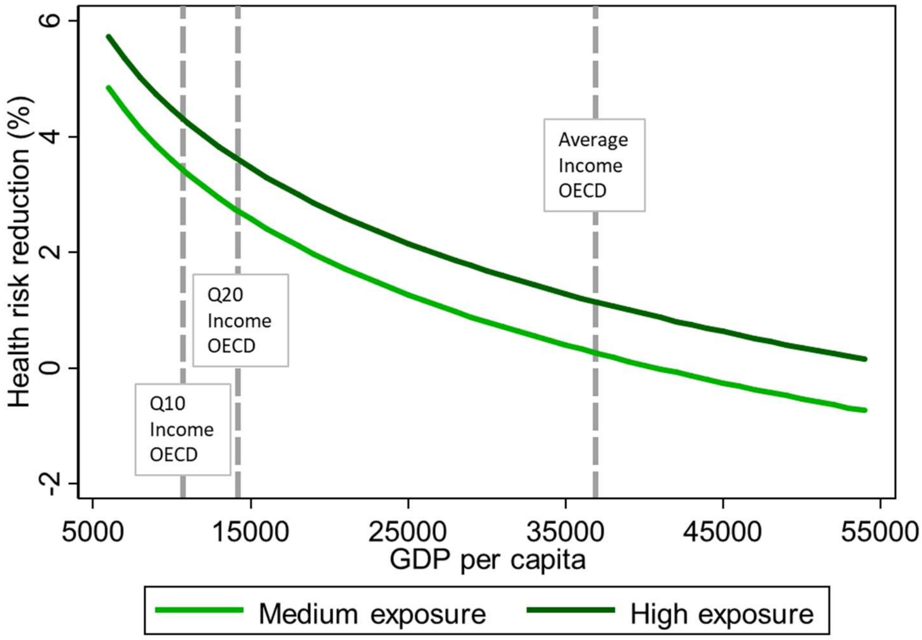

Figure 3.2: *Change in health risk reduction (HRR) in relation to GDP per capita (average) for all-cause morbidity, 10% quantile (Q10) and 20% quantile (Q20). Marginal effects are calculated for mean values of quantitative variables and median values of qualitative ones. Exposure from baseline to high. Source: Own data and OECD Income Distribution Database (via http://oe.cd/idd).*

Investment on green areas may therefore be a strategy to alleviate health inequalities in poor areas. The findings suggest that interventions may require important increases in green space available. Figure 3.3 shows how the relation between per capita income and health risk reduction is approximately flat when medium exposure is analysed while the slope becomes negative for a higher level of exposure. This relation has been built through the simulation of expected health risk reductions for the observations included in the study for all-cause morbidity, using mean values of quantitative variables and median values of the dummy variables of the sample for the marginal effects' calculation.

This result implies that targeting the inequality through development of green spaces may require important developments in neighbourhoods in terms of green infrastructures in order to guarantee high exposure of citizens.

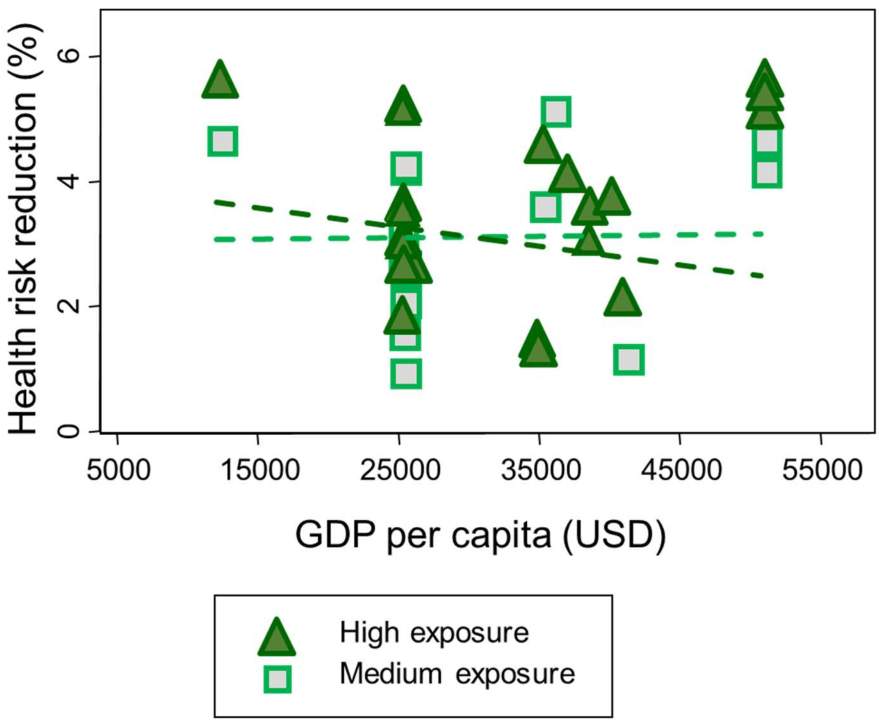

Figure 3.3: *Correlation between GDP per capita and health risk reduction for all-cause morbidity in the study sample. Marginal effects are calculated for mean values of quantitative variables and median values of qualitative ones of the sample. Exposure baseline to high.*

Impacts of the inclusion of green areas are therefore context-dependent, which implies that some areas will have a greater potential to benefit from them. Figure 4 shows which European regions could benefit more from improvements in health arising in these cases. Eastern and particularly south-eastern areas are among those with higher potential for benefits. Among the reasons are the aforementioned impact of income over the relationship. Areas of lower income can benefit more from green areas from the health perspective. Moreover, many of these countries have higher amounts of hospital beds relative to the size of their populations. This measure was introduced as a proxy measure for the size of the health sector and was found to be positively correlated to the impacts analysed. Several areas in the eastern Mediterranean coast have also a higher potential for improvement, possibly due to the high urbanisation of such coastal areas, in a similar manner, central Europe presents high levels of urbanisation and therefore high potential for health risk reduction. On the opposite side, northern Europe has the lowest potential of potential health benefits from increases in green areas. This may be due to higher GDP per capita as well as a more widespread access to green environments, pointing towards diminishing returns to green spaces.

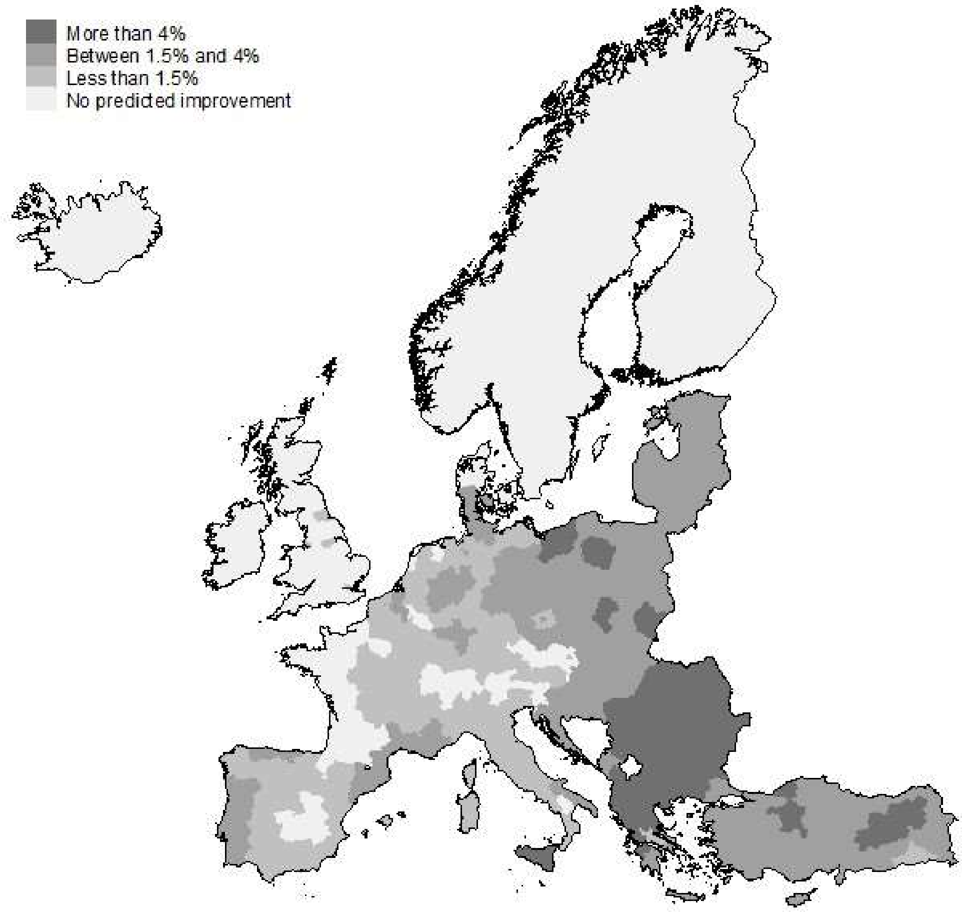

Figure 3.5: *Map showing potential improvements across European NUTS 2 regions.*

3.4 Discussion and Conclusions

The existing literature on the impact of exposure to green areas shows a high level of heterogeneity with respect to both the methods and indicators used for health and exposure to green areas. There have been diverse findings, leading to uncertainty as to the nature of the health benefits from green space exposure. In this context, this study argues that it is important to consider both significant and no-significant results in the literature in order to construct an overall framework to study the relationship between green spaces and health. For this purpose, we performed the following steps: (i) literature review of studies with quantitative results on the health benefits from green areas, (i) construction of a database with standardized indicators for the health outcome and the exposure level, and (iii) econometric analysis using the Heckman Selection model to correct for the unobserved selection bias and analyse key emerging patterns from the literature.

Our results show that, while diverse, studies in the literature tend to find a positive correlation between green spaces and health benefits, especially strong for high levels of exposure. One of the most relevant questions extracted from this analysis is the relevance of contextual factors. The notion that different contexts yield different interconnections is supported by the results obtained, which pointed towards income, education, age or urbanisation as possible factors affecting the results of the different studies. Income was found to be the most relevant one, considering also that the capacity to build and sustain green areas is correlated to it. It is notable that the findings in terms of different health benefits due to context would suggest need for diversity in environmental policy in terms of green spaces.

This has relevant implication over several social aspects. First, it opens a pathway for considering the co-benefits arising from adaptation to climate change using green spaces. The increase in the amount of available green space in urban areas has been proposed in order to adapt to several impacts of climate change such as increasing temperatures (Bowler et al., 2010; Doick et al., 2014; Harlan and Ruddell, 2011) or flood risks (Claessens et al., 2014; Opperman et al., 2009). Such measures are often referred to as Ecosystem-based Adaptation (EbA). The potential for health improvement could arise as a positive side effect or co-benefit of EbA strategies. An area where this could have implications is urban planning. The urban areas in developed countries are increasingly given an ecological perspective and new built areas include public open spaces including green areas. Literature suggests that green spaces are not optimally distributed among all citizens but that wealthier neighbourhoods dispose of higher amount of them (Germann-Chiari and Seeland, 2004; Mitchell and Popham, 2008). Therefore, development of green spaces in poorer neighbourhoods may be used to decrease health inequality within developed countries. Such reductions have direct economic impacts in the form of less medical expenditure, increased productivity and lower work absenteeism.

Yet, the most rapidly urbanising areas are not located in such countries, and are often subject to social, economic and demographic pressures that do not allow for such measures to be implemented. It is precisely these countries, where quantitative studies are scarcer. The model predicts an inverse relation between income and health impacts, though the absence of studies in developing countries poses a pathway for future research. The idea extracted from these results related to the fact that context is highly relevant, is consistent with the general idea that adaptation has a mainly local component and that strategies should be tailored to the specificities of the area where they are applied.

This leads to another conclusion, that the effects of improving health through higher access to green space could lead to direct economic benefits. These benefits could take the previously mentioned forms of decreased medical expenditure, augmented productivity and less work absenteeism, which could be added to other benefits such as increase in property values, diminished flood risk, etc. Comprehensive economic valuations of green spaces that includes their impacts over health should be expected in future analysis. Cost-benefit analyses may otherwise underestimate benefits.

This study has been performed in a field where the literature is growing but heterogeneous. While its intention is precisely to help in the task of having a general overview of the potential health benefits of green spaces in health, the heterogeneity of these studies has implied a reduction on the base for studies included in the present analysis.

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4. Reconceptualising urban adaptation strategies: stakeholders' insights on hard and soft responses to climate change

4.1 Introduction

Targeting climate change related impacts requires a span of action that ranges from local approaches to regional plans of action, but adaptation is regarded as a local-scale issue in most cases. River basins and urban areas represent two important cases of geographic units to be used as reference in adaptation plans. Tackling issues such as flooding or rising temperatures has often been linked with the development of particular infrastructures such as dams or tunnels. While such measures have proven themselves effective, their diversity in terms of the costs they may generate (economic, environmental, spatial, etc.) has risen questions on how to develop more cost-effective options.

Defining participation is a complex task, as different interpretations are used (Few et al. 2007). A workshop meeting has been regarded as a middle-way between public meetings and the more specialised concept of advisory committees (Chess and Purcell 1999). Participatory methods have been proposed in different contexts, with the aim of addressing different aspects of climate change, such as impacts and adaptation (UNFCCC 1992). Not only the context-specificities have been mentioned as arguments in favour of participatory methodologies, but also the higher levels of involvement carried out by those stakeholders that have had the chance of exchanging their views, preferences and experiences (Lynam et al. 2007; Moran et al. 2016). This favours a proper environment for interaction. Communication has become a main issue in science. For scientific findings and recommendations to be relevant adequate reception from stakeholders is needed, either when this receiver is the general public, health professionals, public decision makers or otherwise. Moreover, efficiency can often only be obtained when feedback is possible. Peer feedback is generally not enough to guarantee optimal results.

In this context, it is apparent the need to promote feedback creating networks that not only include experts on the field. This can be translated into the formation of networks that are both multidisciplinary and intersectoral. Multidisciplinarity is necessary in order to achieve diverse perspectives in research. It has been promoted in the last decades from institutions and authorities in order to allow researchers to expand their perspectives and encourage their effectiveness and efficiency. The building of intersectoral webs on the other hand, plays a more relevant role in dissemination of scientifically acquired knowledge. In the case of understanding climate change adaptation, it is often public decisionmakers and officials who need to be aware of new developments. Therefore, fluid and bidirectional communication is essential. As previously introduced, geographical scale is also a relevant issue, as adaptation is mainly a locally implemented policy, though research has a global nature. The ultimate goal is the establishing of a series of both formal and informal networks for information sharing.

In order to obtain a wider understanding and to fulfil the intent of creating an understanding of the matters caused by impacts generated and possible solutions to them, the meeting tried to gather representation from as much sectors as possible. This representation included experts linked to different departments of the City Council of Bilbao, academics and professionals of industries related to sustainable technologies. There is a feedback process. Civil servants may share their experience in different projects and their own forecasts that may help in the development of new strategies and services by the rest of the agents. On the other hand, policymakers may implement those services proposed and benefit from the tools made available by those who have previously used them for scientific development. Integration between both local and scientific knowledge is a vital need of deliberation processes based on stakeholder contribution (Reed 2008; Vignola et al. 2009), though the authors concentrate on the role of involved communities.

The workshop here described and analysed took place organized in December 2014 in Bilbao (Spain), and had the aim of addressing three basic aspects of adaptation measures: (i) identification of the impacts caused by climate change, (ii) proposed adaptation measures implemented by different agents to address those impacts, and (iii) the analysis of costs and benefits of the adaptation measures proposed. This paper has the double objective of addressing impacts of climate change on the local level, with a special focus on health-related aspects, and explaining the process that was followed in order to encourage stakeholder implication on the study. Therefore, a double focus will be made: on one side, the proceedings of the workshop; and on the other the inputs, both individual and collective, of the participants that agreed to collaborate in the project.

The first of these thematic axes lays on the analysis of the impacts of climate change on the area of the Basque Country and the municipality of Bilbao. Any measure prescribed to adapt to climate change must be taken with the highest achievable accuracy the extent, timing and probability of the impacts it must diminish. The second question asked to the participants was on adaptation measures presented as good practices in specific contexts. It must be noted the importance of spreading those procedures that have proven to be efficient in solving a problem, both to be replicated when possible and to serve as inspiration in other cases. Communicating the achievements obtained through innovation may encourage other sectors to pursue their respective objectives through similar measures. Finally, the third axis aimed to study the costs and benefits of measures proposed. Efficiency is not measured only in terms of effectiveness, and therefore economic costs of measures must be taken into the equation, not only in financial terms, but also recognizing the opportunity costs and environmental impacts.

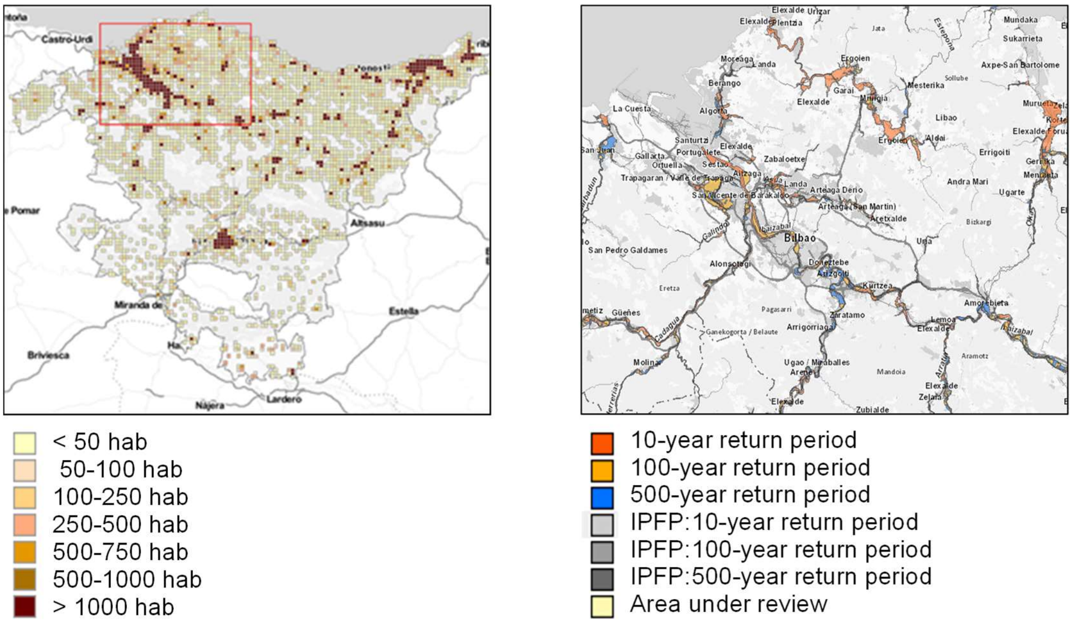
Following this introduction, this paper is divided in four sections: First, chapter 2 introduces the characteristics of the methodology employed, describing in first place the procedure of the development of the workshop and secondly the development of the clustering process for the measures proposed by participants.

4.2 Methodology

4.2.1 Case study context

This study is focused on climate change impacts and potential adaptation measures in the Basque Country, which is located in the Spanish northern coastline. Expected climate change impacts in the area vary, though water is one of the main concerns due to both the present impact of draughts in most of the Iberian Peninsula. These could condition water supply in the area and to the impact of floods, which are among the most damaging natural events in the area. Most of the inhabitants of the Basque Autonomous Region reside in coastal areas or river basins, including the metropolitan area of Bilbao.

Figure 4.1.a shows population density in the Basque region. Densely populated zones can be found around the three capital cities and several corridors. Corridors are mainly articulated along river basins. Figure 4.1.b shows the metropolitan area of Bilbao, the most populated city and conurbation of the region, with a population density of 8,435.5 inhabitants per km2 (EUSTAT 2017), which approximately follows the basins of the Ibaizabal and Nervion rivers between their confluence and the river mouth. The 1983 flooding events affected a significant part of the region, with severe impacts in the city of Bilbao, where various deaths were registered and economic impacts where high. Flood defences have been developed since, but, as can be seen, events of high impact (100-year and over return periods) could have relevant impacts in industrial and inhabited areas. While water-related issues such as salinification of aquifers, draughts and the aforementioned floods may represent the core of climate change impacts in the region, other issues such as heatwave mortality or the expansion of vector-borne diseases may also be relevant in the forthcoming decades.



(a) (b)

Figure 4.1: Population density in the Basque Autonomous Community (4.1.a) and flood risk in the Greater Bilbao area (4.1.b). Source: Eusko Jaurlaritza / Gobierno Vasco. geoEuskadi.

4.2.2 Participatory process to extract local adaptation strategies

The workshop followed the need to inquire into the matter which measures were either being put into practice within the context of the Basque Country or those that could be applied in the region. It had the double purpose of finding some of the measures and promising practices to be found in the area and of making an attempt to estimate their potential costs and benefits. In order to achieve a comprehensive view of the matter, a group of 9 participants was selected among the stakeholders involved. Participants were therefore chosen among three groups of interest: academia –Universities: UCM; UPV/EHU; Basque Centre for Climate Change (BC3)–, private R&D enterprises – SUDS-Atlantis; Tecnalia; Vicomtech-IK4– and the public sector – Bilbao City Council, areas of Health, and citizen Safety and Security–. The workshop was designed not as a public meeting but as a stakeholder-oriented encounter, nevertheless, dissemination of the results was deemed indispensable.

Intensity of involvement and influence of participants must also be discussed (National Research Council 2008; Blondet et al. 2017). The meeting was designed to take profit of participant involvement. Therefore, every participant was given a period for the description of their fields of knowledge, experiences and ideas, therefore encouraging interaction. Influence could be regarded as moderate due to this precise exchange of information.

The workshop was divided into two separate sessions. The first on of them was dedicated to short presentations given by each of the participants. These oral expositions were ordered according to thematic aspects: These sections were headed by the exposition of the impacts expected from climate change in the area of Bilbao and the methodologies proposed for the estimations of these impacts; a second set of speeches proposed different systems, services and protocols that could play a role in the avoidance of the impacts of changing climatic conditions, and therefore serve as adaptation measures against climate change; finally, the session was closed by addressing potential co-benefits obtained through different measures destined to mitigate the emissions from the transport sector.

As previously mentioned, a series of measures were extracted from the participants' interventions. This task was performed by one of the members of the team carrying out the workshop. Measures mentioned explicitly or implicitly were included in the list in order to achieve a comprehensive look and to include as much types of approach as possible. The measures annotated spanned a range of forms, including technological measures, green measures, conventional grey infrastructures, etc. Once the measures were obtained, these were written in a series of posters that were put along the walls of the meeting room.

The second part of the day was designed in order to obtain extract participants' views on the potential costs and benefits of a series of 26 measures and practices that were extracted from the previous round of presentations. This part of the process was performed in a similar fashion to pebble distribution methods (Lynam et al. 2007; Raymond et al. 2009), though in this case, participants were asked to rank the ten measures they considered most costly and those they perceived as more beneficial with colour-coded dots with numeric values over them.

Participants were then given a total of 20 stickers each of them with a number ranging from 1 to 10 and in two colours: green and red. They were then asked to rank with green stickers those measures they found to have more benefits, and with red stickers those they found costlier. After the activity, posters were collected and the punctuations given by participants were transferred to a spreadsheet. The estimates given by participants were later statistically analysed in order to extract general conclusions.

4.2.3 Cluster Analysis

Once the estimates given by participants were assigned to the measures, the following step of this analysis was to group the different measures according to characteristics such as whether the measure was proposed by an academic, a private researcher or a public official, whether the measure referred to urban design, ICTs, grey infrastructures, green adaptation, or risk prevention and meteorological predictions. Once each measure was given a series of parameters based on punctuations and the aforementioned characteristics, all 26 identified measures were classified following methodologies for cluster analysis.

Measures were based on qualitative characteristics and therefore responded to a series of binary qualificative variables. A series of methodologies were considered in order to assign similarity coefficients to each variable and group them into a number of clusters in order to ease the analysis. Among the methodologies considered such as the Simple Matching similarity coefficient (Sokal and Michener 1958), the Kulczynski similarity coefficient, or the Ochiai similarity coefficient (Ochiai 1957). This last system was used in order to group the measures proposed.

$$Eq. 4.1 \qquad s_{ij} = \frac{a}{[(a+b)(a+c)]^{\frac{1}{2}}}$$

Where $\{a, b, c\}$ responds to the table:

		Observation $\boldsymbol{j}$ 1	0
Observ. $\boldsymbol{i}$	1	a	b
	0	c	(d)

Letter d marks the hypothetical combination of neither observation sharing an attribute. Once similarity coefficients were obtained, dendrograms where constructed to visualise the results and to establish a manageable number of clusters for the following analyses.

4.2.4 A Bootstrap approach for simulating perceived cumulative distribution functions

In order to compensate the disparity in the number of votes assigned to each of the measures, new observations were generated in a bootstrap process (Efron 1979; Lahiri 2013). These new observations were generated by taking 10 random samples $(X_1, \dots, X_{10})$ from each of the punctuations given to the measures appearing in each grouping. The average $\overline{(X_\iota)} = \bar{X}(X_1, \dots, X_{10})$ from this secondary sample was taken in order to obtain the new series of observations. This process was repeated 10 000 times, thus generating 10 000 averages ($\bar{X}_1, \dots, \bar{X}_{10\,000}$). form sets of 10 random numbers and therefore a comprehensive series of data.

4.2.5 Efficiency in terms of benefit-cost perceptions

Individual measures were afterwards analysed according to the average weights assigned by participants. Averages were calculated for both costs and benefits. The resulting graph showed four quadrants:

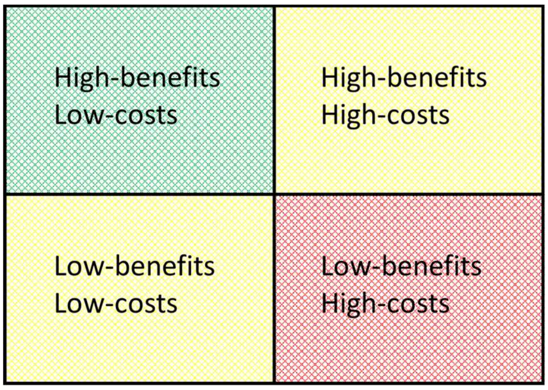


Figure 4.2: Quadrant-based aggrupation of measures proposed.

Measures perceived as most efficient were those situated in the upper-left quadrant, i.e. where perceived benefits where high and perceived costs low, measured as the average of the ranks given by participants. On the opposite side, the bottom-right quadrant contained measures with lower perceived efficiency due to high estimated costs and lowest benefits. Less can be said about the perceived efficiency of measures located in the two remaining quadrants, where either high benefits and high costs or low benefits and costs are expected.

4.3 Results

4.3.1 Overview of contributions and perceptions

Table 4.1 summarizes the 26 measures extracted from the presentations made by participants. This list includes an important amount of measures related to urban planning and design, such as urban green infrastructures, among them Sustainable Urban Drainage Systems (SUDS), which were presented as ways of reducing both surface runoff and the urban heat island effect; soil use planning; urban design features centred on heat-reduction such as the creation of ventilation corridors within urban areas and adequation of building heights; development of urban climate maps that ease urban planning; and setting-based integral planning of cities. Another group of measures could be regarded as focused on risk prevention and management of emergency situations, like improvements in emergency and response plans, Early Alert Systems (EAT), air quality monitoring, development of efficient communication networks between emergency teams and citizens, and semi-automatized text analysis of social network contents orientated towards improved emergency response capacity. These last two measures were also based in ICTs.

Table 4.1: *List of measures extracted from participants' inputs.*

Id	Adaptation measures described by participants
1	Flood prevention measures (Infrastructures)
2	Improvements on the water network: leakage and expenditure control
3	Soil mantle improvements
4	Preventive pest control
5	Improvements on emergency response plans
6	Early alert systems
7	Improvements on air quality monitoring
8	Economic incentives and counselling for municipalities
9	Urban green infrastructures
10	Soil use planning
11	Development of adaptive follow-up indicators
12	Basin-scale vegetation management for flood prevention
13	Urban planning and design based on an increased thermal comfort for pedestrians.
14	Introduction of wind corridors and optimizing building height
15	Urban heat maps for urban planning (collaboration between climatologists and urban planners)
16	Sustainable Urban Draining Systems (SUDS)
17	Evaluation of ecosystems and their multifunctionality for the application of economic incentives
18	Integrated urban planning that takes into account its context
19	Natural and semi-natural spaces for a resilient area
20	Improvements on meteorological prediction
21	Improvements on emergency plans
22	Main drainage infrastructures
23	Reliable communication networks between emergency teams and citizens
24	Semi-automatic analysis of comments (information) in social media to shorten response timers
25	Decarbonization of transport through behavioural changes
26	Decarbonization of transport through technology

A first analysis of the measures perceived by stakeholders as those with higher benefits showed that grey infrastructures such as the above mentioned "grey" drainage infrastructures (e.g. storm sewages) were still regarded as measures with high effectiveness (10 positive votes), even if the high costs diminish their net benefit. Their sustainable counterpart, SUDS (Sustainable Urban Drainage Systems), was also regarded as beneficial by many of the participants (8 positive votes). Among the other measures with high expected benefits we can highlight the decarbonization of transport through changes in behaviour such as the use of alternative transports like bicycles (7 votes), urban planning and design where thermic comfort is considered (7 votes), or the use of natural and semi-natural environments to increase resilience (4 votes).

On the side of expected costs those highlighted by participants also varied in among the different types of solutions proposed. While decarbonization of transport through changes in behaviour was regarded as a measure with high return at low cost, decarbonization of transport through technological changes was perceived as a costly measure (7 votes) with lower return. Participants found flood prevention through modification of infrastructures as a costly measure (6 votes), just as soil-use planning. It is also important the weight given by participants to the costs derived from economic incentives and advising municipalities in order to incentivize the protection of ecosystem services (4 votes).

4.3.2 Clustering the measures

Figure 4.3 (a-d) shows the dendrograms obtained through the classification of the measures selected. The Ochiai coeffcient (Ochiai 1957) was taken so that all 26 measures could be divided in groups of similar characteristics. Measure were clustered into six groups of between two and seven of them. An outlier (soil mantle improvements [3]) was discarded. The first of the groups contains mostly **grey measures**, such as infrastructures for flood prevention [1] -Measure Id 1 as appearing in Table 4.1-, leakage and expenditure control in water networks [2], and main drainage infrastructures [22]. A second grouping was created including several **preventive measures** such as preventive pest control [4], improvements on emergency response plans [5], early alert systems [6], improvements on emergency plans [21], reliable communication networks between emergency teams and citizens [23], and semi-automatic analysis of social media content to shorten disaster response timers [24]. The third group included two **non-ecosystem-based adaptation and mitigation** measures: The development of adaptive follow-up indicators [11], and the decarbonization of transport through technology [26]. The fourth and most numerous group is dominated by **research and environment** related measures, and includes improvements on air quality monitoring [7], improvements on meteorological prediction [20], basin-scale vegetation management for flood prevention [12], the evaluation of ecosystems and their multifunctionality for the application of possible economic incentives [17], urban planning and design based on an increased thermal comfort for pedestrians [13], integrated urban planning that takes into account its regional context [18], and the use of urban heat maps for urban planning [15]. The fifth cluster was formed by **green adaptation and mitigation measures** and captured measures as economic incentives and counselling for municipalities [8], the use of natural and semi-natural spaces for the creation of resilient areas [19], decarbonization of transport through behavioural changes [25]. urban green infrastructures [9], and Sustainable Urban drainage system (SUDS) [16].

Finally, the sixth and last cluster grouped two measures linked to **urban planning**: soil use planning [10], and introduction of air corridors in urban areas [14].

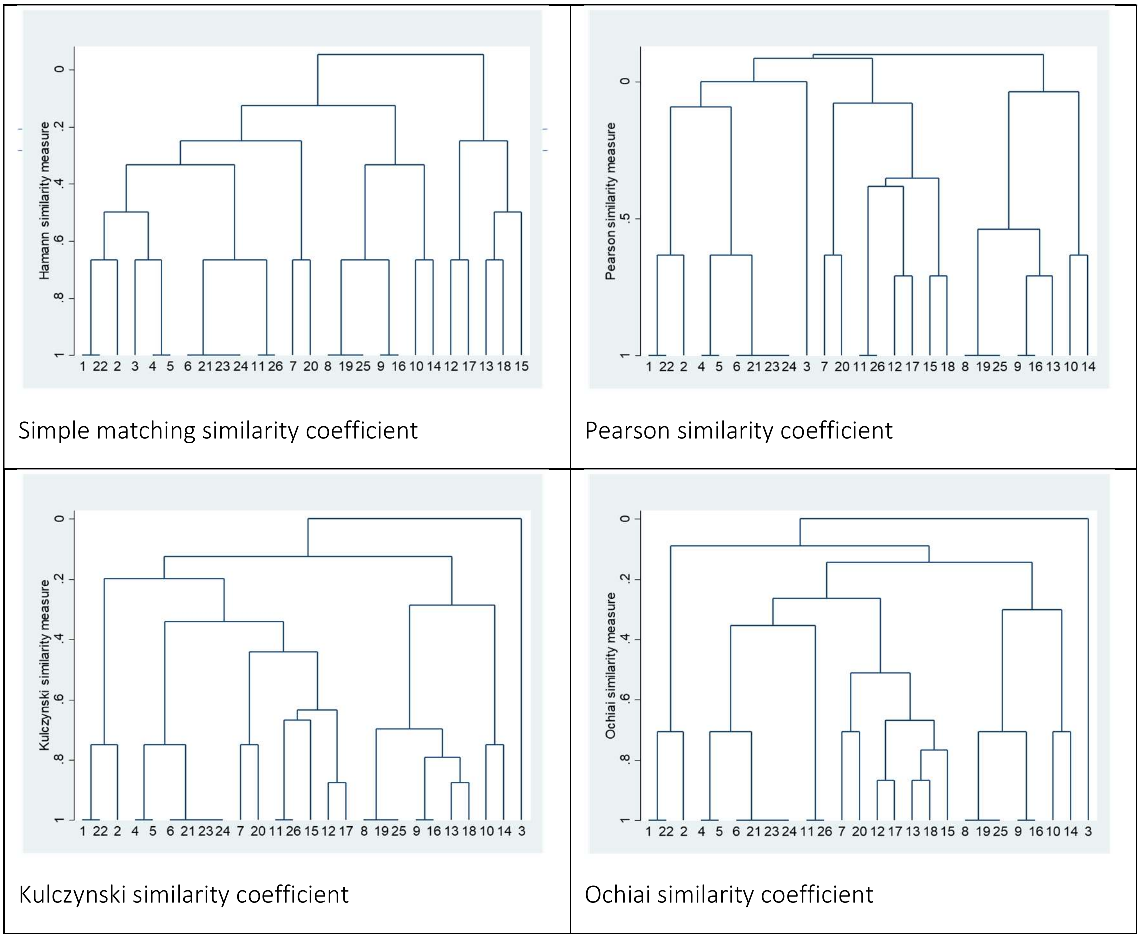


Figure 4.3: Several dendrograms showing the results of the clustering. Differences in weights implied slight changes in grouping in cases irrelevant for this analysis. The grouping was based on the results given by Ochiai's coefficient (d) (Ochiai 1957).

Once the grouping process was made, average costs and benefit ranks assigned were displayed in order to visualize the estimation of associated costs and benefits, making comparison easier. Figure 4.4.a and 4.4.b show, respectively, graphic dispersion of values assigned to the measures contained in each of the clusters. These graphs show high costs and benefits assigned to grey measures, higher than other estimations. Next in estimated benefits are green adaptation and mitigation measures, which also appear as notably higher than the other groups and significantly higher than three of them. Among the rest of the groups, research and environment related measures appear as the third most beneficial group, followed by urban planning, non-ecosystem-based adaptation and mitigation and finally the preventive measures cluster. On the side of perceived costs, green adaptation and mitigation measures appear again second, though the differences between this cluster and the rest are less. Non-ecosystem-based adaptation and mitigation are the next group in perceived costs, followed by preventive measures, urban planning and, finally, research and environment related measures, which are perceived as less costly.

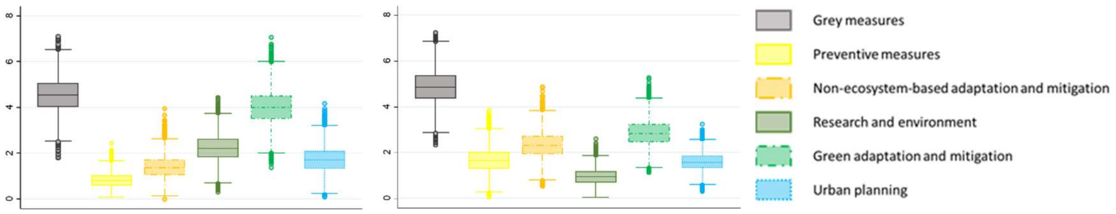


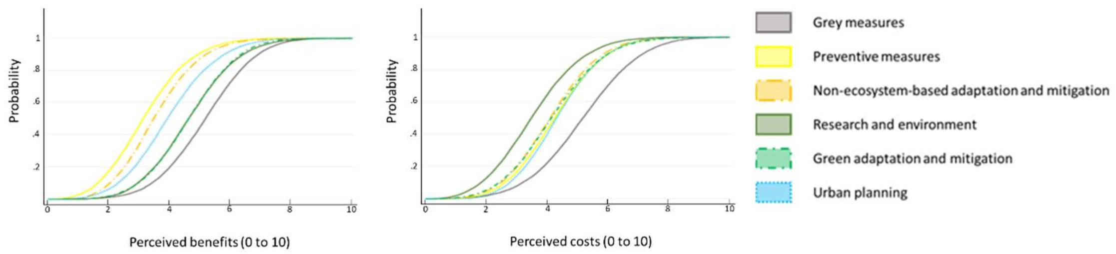
Fig. 4.a Fig. 4.b

Figure 4.4: The distribution of the stated perceptions held by participants over benefits of different measures included in the group (Figure 4.4.a). Perceived cost estimations are plotted following (Figure 4.4.b).

4.3.3 Measuring consensus among participants' views

Figures 4.5.a and 4.5.b show the cumulative distribution functions of, respectively, perceived costs and benefits as sampled from the bootstrapping process. The distribution patterns are coherent with previous measures. The position of the curves corresponds to the average benefits and costs estimated for each group, while the shape tells us that the distribution of these results is relatively similar among them.

Information management and emergency plans show low scores in both benefits and costs, with emergency plans having lower variance. Grey infrastructures, EbA and measures easing mitigation show high expected benefits with higher variance in the last group. Estimated costs show higher spread, though in neither of the cases changes in distribution of benefits/costs are apparent further than to allow for the ordering of estimations. While the value of urban green areas has been analysed extensively in the literature, there is still a lack of confidence over their beneficial impacts. Risk-averse policy makers may avoid such measures due to such subjective uncertainties (Lempert et al. 1996; Webster 2003). Nevertheless, it appears that the most specific interventions, such as those grouped in the fifth cluster are perceived as high-benefit measures.



(a) *(b)*

Figure 4.5: Cumulative distributions of estimated benefits (Fig. 4.5.a) and costs (Fig. 4.5.b) obtained through a bootstrapping process.

4.3.4 Assessing efficiency according to stakeholders' perceptions

A view of individual measures and their associated costs and benefits can be obtained by plotting them in a two-dimensional space (figure 4.6). Higher values of the y axis are related with high perceived benefits; while high values for the x axis relate to high perceived costs. Lines highlighted in each axis represent average values for each of the dimensions. As for the groups created, it can be seen that grey measures are all three of them located in the high-benefit/high-cost quadrant. The high-benefit-low-cost quadrant includes four measures, urban green infrastructures [9], the use of natural and semi-natural spaces for the creation of resilient areas [19], using of urban heat maps for urban planning [15], and basin-scale vegetation management for flood prevention [12]. All four are included in clusters four, research and environment related measures, or five, green adaptation and mitigation measures. Initiatives grouped in clusters two (preventive measures), tree (non-ecosystem-based adaptation and mitigation) and six (urban planning), occupy the low-benefits quadrants, spread between different levels of estimated costs. Measures such as preventive pest control [4], soil use planning [10], and the application of possible economic incentives [17] were located in the low-benefit/high-cost quartile. On the other hand, measures such as improvements on emergency plans [21], increased thermal comfort for pedestrians [13] and the introduction of air corridors in urban areas [14] were perceived as having both lower benefits and costs.

It can be underlined that determined green measures can be an essential part of win-win strategies. Such measures are often less expensive than their "grey" counterparts and can report both direct and indirect benefits. Direct benefits as adaptative or mitigating measures themselves on the one hand, and indirect benefits through the improvement of urban and periurban aesthetics, carbon sequestration and mitigation, etc. on the other. These strategies can be framed within the "triple dividend of resilience" concept, which would classify in this case the benefits from adaptation into damage avoidance (reducing human and material losses), unlocking the economic potential (by incentivising investment in formerly risky areas), and creating co-benefits (such as increasing the aforementioned aesthetic values of certain areas, climate change mitigating effects, improving weather forecasting, etc.).

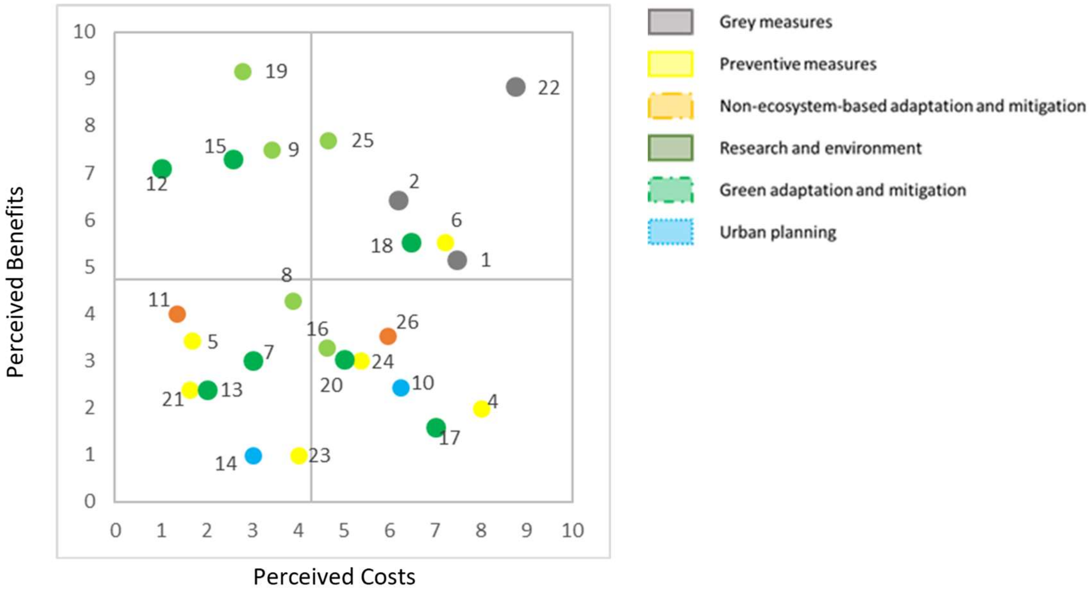


Figure 4.6: Measures plotted according to the averages of their respective costs and benefits.

4.4 Discussion and conclusions

This paper has analysed the outputs extracted from the workshop performed in Bilbao with the aim of gathering some experts from diverse fields that dealt in different ways with climate change impacts and adaptation measures. These outputs consisted on a series of possible measures designed to cope with different impacts that could potentially have an effect over populations in the Basque Country and similar areas where flooding and droughts might inflict severe damages in population and the environment (Karlo and Sajna 2017). These measures were afterwards ranked by participants according to the potential benefits and costs they could carry. After a statistical analysis, the outputs showed specific trends in perceptions stated by the involved experts.

During the last years a wide variety of stakeholders has developed an increasing number of adaptation measures and strategies in a context where climate change impacts have already started to unveil. While several ideas appear more persistently over those strategies, diversity is a needed characteristic due to local particularities and variety on expertise types and perceptions of those designing and implementing them. Therefore, we have presented a way of clustering them into a few groups in order to ease the analysis. While this result may be context dependent, the tools employed may be used in order to analyse perceptions and strategies to be implemented in a wide range of areas and situations.

The most meaningful result is the tendency towards assigning higher benefits and lower costs to measures related to researching environmental tools and Ecosystem-based

Adaptation (EbA) (Secretariat of the Convention on Biological Diversity 2009; Vignola et al. 2009; IPCC 2014), and those that could have a positive impact over climate change mitigation. On the one hand, the benefits of the ecosystem have been analysed throughout the years, and it has been observed that the linkages between the environment and livelihoods are varied and often strong. The Ecosystem Services model proposed in the Millennium Ecosystem Assessment shows the importance of these links by analysing the different goods and services provided by the environment. Among them it is possible to find ways in which natural ecosystems protect human ecosystem. Green infrastructure has an important role in this sense. Urban development strategies may use such infrastructures in order to reduce the Urban Heat Island (UHI) effect (Brown et al. 2015), to increase soil permeability and reduce runoff both under heavy rains and under flood hazard (Cheng et al. 2017). Water regulation, including protection against flooding should be mentioned due to its relevance in the context of the Basque Country, due to the aforementioned threat of diminishing water resources and the increase in flood-related risks in the area.

While it can be argued that big “grey” infrastructures have also high benefits and that they may be necessary in order to avoid certain damages, they are often perceived as costly measures. In parallel, strategies centred in information management, where many ICT-related measures were allocated, scored low in both potential benefits and costs, in the same way as emergency planning. This might be the result of stakeholders perceiving an important need to take ex ante measures that reduce the risks of harmful events affecting the population in contrast to response plans. Uncertainties too can play an important role on adaptation strategies. As previously introduced, the use of ecosystem-based alternatives is often regarded as a more effective strategy, which, in combination with reduced costs makes such adaptation paths as tools to be considered when designing adaptation strategies, as it can provide means capable of building win-win strategies that reduce adaptation costs while providing both adaptive and mitigating benefits.

Participatory workshops are an important tool in the design of climate change adaptation policies, though they cannot, by themselves provide all information needed for the design of effective and efficient adaptive measures. The intention of this research step was not only to enumerate the views of different experts but also to provide communication links among academia, private entities and policymakers. The importance of such links has been stated along the literature on participatory research, but the identification of the outcomes arising from these links is a more complex matter.

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5. Discussion and conclusion

The current dynamics of climate change make it necessary to operate from the perspective that a combination of efforts have to be made in terms of both adaptation and mitigation, not only in the future, but also in the present. Several impacts of climate change are either unavoidable or already occurring. Within the existing adaptation strategies, this work has tried to analyse those based in ecosystem promotion, particularly green areas and has found some evidence on their impacts over human health.

Literature on health impacts of natural and seminatural areas is a growing corpus. It is also an area where diversity in methodologies and perspectives exists: studies have been performed combining different statistical tools, health perspectives and their understanding of exposure to the environment. Studies that take a theoretical perspective were also fundamental in order to structure a body of evidence. This diversity offers a clear benefit in generating stronger evidence, but makes it difficult to reach a general overview of impacts in a qualitative manner.

Nevertheless, as it is stated in Chapters 2 and 3, evidence in favour of a net positive trend has been detected in the literature in this study. This implies that there is both quantitative and qualitative evidence in the literature supporting a positive health effect on health of natural and seminatural environments. Proof on how health impacts are distributed over different aspects of health (mental health, respiratory health, etc.) is still non-homogeneous due in part to the different levels of attention gathered by each field.

A relevant implication of these findings is the existence of economic impacts of different type. First, due to the loss of productivity that illnesses cause, improvements in health have the potential of increasing productivity. Lack of health has also direct costs that can be avoided by several means, including prevention against potential changes in the geographical distribution of vectors. Diseases are also related to uncertainties, which, in absence of insurance systems can be another source of loss of wellbeing from the economic perspective.

This brings us back to the issue of inequalities. The higher health improvements observed in income deprived and vulnerable populations could help relieving the gap in health equality caused by several environmental and social conditions (Hilmers et al. 2012; Alkon et al. 2013; Black et al. 2014). Nevertheless, in order to take profit from this capacity, the distribution of green spaces must be taken into account, as it has been observed that wealthier neighbourhoods often account for most of the green space available in cities (Germann-Chiari and Seeland 2004).

Also, efficiency is a relevant issue when discussing the economic implications of developing green spaces. Health co-benefits such as those registered in the literature add value, and therefore contribute to their efficiency. Uncovering all benefits of projects classified as EbA is an impossible task, but obtaining adequate estimates of each of the impacts is vital for adequate decision-making.

It is relevant to mention, as extracted from Chapter 2, the relevance of context further than the economic background. Demographic issues have also been considered in the literature. Issues such as population density, ageing, proportion of urban dwellers or climatic considerations may result determinant in shaping the links between the environment and human health. Factors such as income play a role here, but are not the only. The relevance of a region or country's approach towards health, for example, was also found to be significant, which led to apparent regional disparities between eastern and western Europe in a way similar to that described in forest management literature (Živojinović et al. 2015; Feliciano et al. 2017). Therefore, taking them into account has been key in this study and should also be crucial in further research both in the small-scale analysis and in studies involving larger regions.

5.1 Discussion

There are still many questions with regard to the evaluation of health impacts of natural and seminatural spaces. One of the main pending issues is to move into a research corpus where comparison among studies is easier. This could imply facing the abovementioned trade-off between diversity and comparability. Nevertheless, it is also needed in order to allow for confirmation or refutation when pertinent. One of the limitations of the present study has been the loss of accuracy derived from the need to homogenise results appearing in the literature. It has also implied discarding several valid studies due to their methodologies.

Literature in this field is prominently based in first-world populations. This poses another question to consider. It has been addressed in the literature that impacts are context-dependent. Therefore, it is necessary to consider in a separate manner how the relation works in developing countries. This is particularly relevant as such countries are those showing a faster transition between rural and urban societies. As occurred in Europe during the 19th and 20th centuries, this transition often lacks order and coordination, implying the appearance of slums and sub-standard housing, phenomena with stark implications over human health and wellbeing. Applying knowledge based on already developed areas in developing regions may not bear the expected consequences and therefore, research based in such areas should be broadened.

While it has been addressed in the literature, the mediating impact of active lifestyles over the link between natural and seminatural environments and human health is yet a field where research can and should focus. Results from the existing literature (Pretty et al. 2005; Astell-Burt et al. 2014; Lachowycz and Jones 2014) are yet scarce for relevant research question. Promoting active lifestyles is an issue that has gained relevance in public health agendas and might continue this trend if predictions related to the spread of NCDs are fulfilled. The question of whether social activities also pose a mediating function can also gain attention as populations grow in age.

The work here presented was focused on adaptation to climate change. This means that climate change mitigating efforts have been omitted. The interconnections between mitigation, natural and seminatural environments, and human health and wellbeing are, nevertheless, relevant. Green spaces may work as a carbon sink, but could also promote more active lifestyles that could include commuting by bicycle or walking. Such choices would improve health by increasing physical activity as well as through the reduction of pollutants emitted to the urban atmosphere.

Another pending consideration is the two approaches that could be taken when analysing impacts on inequality, being the first the reduction of inequality within a country or region and the second the decrease of the inequality among countries and regions. Distinguishing how the use of natural and seminatural spaces as adaptation measures against climate change affects each of these aspects is of high relevance. Most of the literature here analysed has either the focus on developed countries, urban green spaces or both. Therefore, more research will be needed on this area.

There are several limitations of this study that have to be mentioned. The main limitation is the likely existence of a publication bias in the existing literature, i.e. that studies showing counterintuitive and nonsignificant results have not reached publication and therefore are not included in the sample. This bias has an impact over several fields and affects the results of qualitative and quantitative literature reviews and metanalyses. It was therefore particularly relevant to include nonsignificant results in the calculations made for Chapter 3. More and more rigorous research (Lee and Maheswaran 2010; Kondo et al. 2018) will be needed to in order to offer more precise estimations.

Another limitation is derived from the static nature of this research. While the studies reviewed span through a decades-long period, most of them have a static approach, and those that take dynamic approaches do not offer enough insights to extract conclusions over the time variable. Studies like the one performed by Alcock et al. (2014) are an exception, though further analysis is required in this direction. Also relevant in order to introduce dynamic components in this area is the issue of discount rate. The approach taken in this sense is a common ground of discussion in climate change literature and also should be considered in further developments.

Future perspectives also affect themselves research. Questions such as how the environment will evolve, or how humans will develop have to be considered. Some of these questions have been answered in the literature relating Shared Socioeconomic and Representative Concentration Pathways (SSP and RCP respectively). The scenarios constructed thorough these narratives allow to project demographic and socioeconomic variables, relating them to climate change inducing gas concentrations (CO_2 equivalent).

Long-term planning should consider the evolution of these variables, but also others, such as the evolution of disease bearing vector's geographical distribution or the changes in NCD incidences, the first of these being closely linked to climate change.

Future research on this field will require multidisciplinary approaches. This is an environmental health issue, which implies that has to be analysed from a specific health perspective, but that is also related to the environment itself, which depends on biological and physical conditions. As previously mentioned, it is an issue with severe implications over the economy, but that has often to be handled by urban designers and local decisionmakers. Therefore, cooperation is needed not only among researchers, but also with public and private institutions in charge of implementing adaptation strategies.

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Annex A

The following table shows a classification of all studies identified in the literature review, among them those analysed in the main manuscript. Due to diversity of methodologies references may appear more than once. Bibliographic information appears in the following pages.

Table A: *Classification of studies used in the review process.*

	Theoretical studies	Quantitative studies			Literature reviews
		Subjective measuring	**Objective measuring**	**Proxi measures**	
General health	(Ashbullby et al., 2013; Carter and Horwitz, 2014; Conradson, 2005; Dean et al., 2011; Dora et al., 2015; Douglas, 2012; Kearns and Collin(Hopkins 2010)s, 2000; Lee et al., 2015; Milligan et al., 2004; Nieuwenhuijsen et al., 2014; Rook, 2013; Sarkar and Webster, 2017; Summers et al., 2012; Van Kamp et al., 2003; Ward Thompson, 2011; Wilson, 2003; Younger et al., 2008)	(Doyle et al. 2006; Pampalon et al. 2006; Mitchell and Popham 2007; Wheeler et al. 2012; De Jong et al. 2012; Mansor et al. 2012; White et al. 2013; Dunstan et al. 2013; Putrik et al. 2014; Carter and Horwitz 2014; Triguero-Mas et al. 2015; Akpinar et al. 2016)	(Takano et al. 2002; Huynen et al. 2004; Pampalon et al. 2006, 2010; Maas et al. 2006; Mitchell and Popham 2008; Poudyal et al. 2009; Villeneuve et al. 2012; Henke and Petropoulos 2013; Lachowycz and Jones 2014; Casey et al. 2016)	(Doyle et al. 2006; Dadvand et al. 2012a, b, c, 2016; Mytton et al. 2012; Richardson et al. 2013; Casey et al. 2016; Cusack et al. 2017)	(Van Kamp et al. 2003; Maller et al. 2006; Tzoulas et al. 2007; Barton and Pretty 2010; Bowler et al. 2010a, b; Lee and Maheswaran 2010; Dean et al. 2011; Thompson Coon et al. 2011; Detweiler et al. 2012; Hough 2014; Lovell et al. 2014; Sandifer et al. 2015; Van den Berg et al. 2015; Gascon et al. 2016; MacBride-Stewart et al. 2016)
Mental health	(Van den Berg et al. 2003; Cole and Hall 2010; Stigsdotter and Grahn 2011; Ashbullby et al. 2013; Beil and Hanes 2013; Sturm and Cohen 2014; Carter and Horwitz 2014; Lee et al. 2015)	(Stigsdotter and Grahn 2003; Grahn and Stigsdotter 2003; Stigsdotter 2004; Nielsen and Hansen 2007; Hansmann et al. 2007; Fuller and Gaston 2009; Mansor et al. 2012; Annerstedt et al. 2012; Roe et al. 2013; White et al. 2013; Ward Thompson et al. 2014; Flouri et al. 2014; Carter and Horwitz 2014; Triguero-Mas et al. 2015; Finlay et al. 2015; Akpinar et al. 2016; Van Den Berg et al. 2016; Min et al. 2017; Firdaus 2017)	(Rodiek 2002; Pretty et al. 2005; Pampalon et al. 2006; Guite et al. 2006; Kerr et al. 2006; Morita et al. 2007; Maas et al. 2009b; Roe and Aspinall 2011; Berman et al. 2012; Astell-Burt et al. 2013; Marselle et al. 2013; Amoly et al. 2014; Putrik et al. 2014; Beyer et al. 2014; Balseviciene et al. 2014; Nutsford et al. 2016; De Vries et al. 2016; Min et al. 2017)	(Rodiek 2002; Pretty et al. 2005; Ward Thompson et al. 2012, 2014; McKenzie et al. 2013; Richardson et al. 2013; Roe et al. 2013; Triguero-Mas et al. 2015; Gidlow et al. 2016)	(Velarde et al. 2007; Thompson Coon et al. 2011; Sandifer et al. 2015; Gascon et al. 2016)

Respiratory health	(Escobedo et al. 2011)		(Pampalon et al. 2006; Maas et al. 2009b; Richardson and Mitchell 2010; Villeneuve et al. 2012)		(Gascon et al. 2016)
Cardiovascular health			(Pampalon et al. 2006; Hu et al. 2008; Mitchell and Popham 2008; Maas et al. 2009b; Richardson and Mitchell 2010; Villeneuve et al. 2012; Hanski et al. 2012)	(Giles-Corti et al. 2005; Doyle et al. 2006; Nielsen and Hansen 2007; Tilt et al. 2007; Witten et al. 2008; Bjork et al. 2008; Li et al. 2011; Almanza et al. 2012; Annerstedt et al. 2012; Richardson et al. 2013; Wilker et al. 2014; Astell-Burt et al. 2014; Grazuleviciene et al. 2014, 2015; Tamosiunas et al. 2014; Dadvand et al. 2015; Kim et al. 2016; Gidlow et al. 2016)	(Pereira et al. 2012; Tamosiunas et al. 2014; Gascon et al. 2016)
Other health problems	(Escobedo et al. 2011; Gentry-Shields and Bartram 2014)	(Doyle et al. 2006);	(Pampalon et al. 2006; Mitchell and Popham 2008; Maas et al. 2009b)		(Gascon et al. 2016)

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