TESE DE DOUTORAMENTO

THE TRANSITION OF FOOD CONSUMPTION TOWARDS SUSTAINABLE PATTERNS BASED ON ENVIRONMENTAL, ECONOMIC AND NUTRITIONAL ASPECTS

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THE TRANSITION OF FOOD CONSUMPTION TOWARDS SUSTAINABLE PATTERNS BASED ON ENVIRONMENTAL DN NUTRITIONAL ASPECTS

Profesora Sara González García y Profesor Gumersindo Feijoo Costa

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ABBREVIATIONS

AD	Atlantic Diet
AWARE	Available WAter REmaining
CF	Carbon Footprint
CPI	Consumer Price Index
DALY	Disability-Adjusted Life-Years
DEA	Data Envelopment Analysis
DMU	Decision making Unit
EFA	Essential Fatty Acids
FU	Functional unit
GD	Galician Diet
GHG	Greenhouse Gas
IPCC	International Panel on Climate Change
LCA	Life Cycle Assessment
MD	Mediterranean Diet
MRV	Maximum Recommended Value
NCD	Non-Communicable Diseases
NRD9.3	Nutrient Rich Diet 9.3
NRF	Nutrient Rich Food
NRn	Nutrient Rich $_{nutrient}$
PEFCR	Product Environmental Footprint Category Rules
RDV	Recommended Daily Value
SDG	Sustainable Development Goal
SFS	Sustainable Food System
SNRD	Sustainable Nutrient Rich Diet
SVGD	Semi-Vegetarian Diet
TP	Tipping Point
VD	Vegan Diet
VGD	Vegetarian Diet
WF	Water Footprint

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RESUMO

RESUMO

Nas últimas décadas a presión sobre o planeta terra por parte dos humanos foi aumentando de modo exponencial ata hoxe en que a Terra está a ser explotada moito máis alá das súas capacidades, superando as posibilidades de rexeneración de recursos naturais. O crecemento global da poboación, o aumento dos ingresos e a urbanización unen forzas para representar serios desafíos para os sistemas alimentarios e agrícolas, mentres que os recursos naturais adoitan ser máis limitados para apoiar esa prestación de servizos. Como resultado, a presión sobre os diferentes ecosistemas é enorme e os impactos ambientais causados na terra, o aire e o mar non teñen precedentes. Neste contexto, o sistema alimentario é un dos principais contribuíntes ao cambio climático xa que é responsable de aproximadamente un terzo das emisións globais de Gases de Efecto Invernadoiro (GEI) procedentes de fontes antrópicas.

A pesar do gran impacto que a produción de alimentos ten no medio ambiente, cómpre ter en conta que os de orixe animal son os responsables da maioría destas presións. Ademais, a calidade e seguridade dos alimentos tamén corren un grave risco en todo o mundo, xa que cada ano millóns de persoas teñen fame, desnutrición, padecen enfermidades graves ou morren como resultado. É por esta razón que é máis urxente que nunca acadar un sistema alimentario sostible que sexa respectuoso co medio ambiente, que ofreza seguridade e calidade alimentaria a toda a poboación mundial e, ao mesmo tempo, sexa social e economicamente aceptable. Para iso, os cambios nos patróns alimentarios actuais son unha das ferramentas máis poderosas e eficaces. A adhesión ás dietas tradicionais, baseadas principalmente no consumo de produtos de orixe vexetal e o consumo limitado de produtos de orixe animal e ultra-procesados, considérase como a pedra angular para acadar este obxectivo. Así, esta tese ten como principal finalidade analizar diferentes patróns de consumo de alimentos desde o punto de vista ambiental, nutricional e socioeconómico, e propoñer as medidas axeitadas para lograr patróns dietéticos más sostibles. Ademais, o proceso de produción de alimentos tamén se analiza en profundidade mediante a análise do ciclo de vida de produtos agro-alimentarios relevantes. Para este propósito, este documento divídese en cinco seccións, as cales vanse a explicar a continuación.

A primeira sección está composta polo Capítulo 1 e polo Capítulo 2 e está dirixida a proporcional aos posibles lectores unha visión xeral do estado do arte do problema que se abordará nesta tese, así como as ferramentas de avaliación metodolóxicas empregadas para este fin.

Capítulo 1: Estado do arte.

Este capítulo céntrase no estado da arte do campo estudado. Así, a situación planetaria actual descríbese dende un punto de vista multidisciplinar. Nun primeiro lugar desde o punto de vista ambiental, profundando sobre todo nos impactos ambientais derivados do sistema alimentario e do consumo de alimentos en xeral. A continuación,

descríbese o estado da calidade e seguridade alimentaria no mundo, así como os efectos directos que ten a alimentación sobre a saúde. Despois enuméranse as características dun sistema alimentario sostible, considerando as principais achegas científicas para adoptalo, e como a adopción dun sistema alimentario sostible contribuiría a avanzar no marco de todos os obxectivos de desenvolvemento sostible. É importante mencionar, que a adherencia a dietas sostibles é unha das ferramentas máis potentes para conseguir un sistema alimentario sostible; por este motivo, neste capítulo descríbese detalladamente tres exemplos deste tipo de dietas como son a dieta Mediterránea, a dieta Atlántica e a dieta de Saúde Planetaria. Finalmente neste primeiro capítulo tamén se presentan os obxectivos e a estrutura xeral desta tese, incluíndo as diferentes seccións e capítulos que a compoñen.

Capítulo 2: Ferramentas de avaliación ambiental e nutricional.

Neste segundo capítulo da primeira sección, continúase coa contextualización, para neste caso dar paso á descrición das ferramentas metodolóxicas utilizadas ao longo da tese. Así pois, nun primeiro lugar detállase a metodoloxía de avaliación de impactos ambientais de Análises de Ciclo de Vida, incluíndo as súas principais etapas como son a definición do obxectivo e alcance, a análise de inventario de ciclo de vida, e a avaliación e interpretación do impacto ambiental. Neste contexto, profúndase no indicador da pegada de carbono, xa que será a referencia ao longo de todo o documento. Neste contexto, profúndase no indicador da pegada de carbono, xa que será a referencia ao longo de todo o documento.; estes son o Nutrient Rich Index, o Nutrient Rich Diet 9.3, o Health Score, e o Sustainable Nutrient Rich Diet 9.3. En último logar, tamén se describe a metodoloxía de Análise por Envoltura de Datos, xa que esta servirá de apoio para a estimación da eficiencia de patróns dietéticos dese unha perspectiva multicriterio.

A segunda sección da tese titúlase "a Dieta Atlántica" e estase formada por tres capítulos (Capítulo 3 a Capítulo 5). A Sección II céntrase na análise ambiental e nutricional da dieta Atlántica, así como nos patróns actuais de consumo de alimentos pertencentes ás áreas onde tradicionalmente se atopa esta dieta como son Galicia e o norte de Portugal. Deste xeito, o obxectivo principal é avaliar a desviación que existe entre o impacto ambiental e nutricional das recomendacións tradicionais da dieta Atlántica e os actuais patróns de consumo alimentario. A información contida nestes capítulos, así como os principais resultados explícanse a continuación.

Capítulo 3: Na procura dun patrón dietético atlántico saudable e respectuoso co medio ambiente: pegada de carbono e calidade nutricional.

Este capítulo céntrase no estudo da dieta atlántica, como o patrón dietético tradicional máis común no noroeste de España. Esta dieta considérase unha dieta saudable de referencia en todo o mundo e caracterízase principalmente por un abundante consumo de produtos de orixe vexetal así como de produtos frescos e de tempada, cociñados dun xeito sinxelo. O consumo de carne (principalmente carne de vaca e porco) e ovos é razoable e o aceite de oliva considérase a principal fonte de graxa para cociñar e condimentar. Neste sentido, o capítulo 3 ten un dobre obxectivo: cuantificar a pegada de carbono da dieta atlántica a través dun enfoque de análises de ciclo de vida asociado á produción, distribución e consumo dos diferentes alimentos que compoñen esta dieta, á vez que se identifica a súa calidade nutricional. Consideráronse o patrón dietético atlántico recomendado e os datos de inxestión correspondentes. Destacaranse as principais causas das emisións de gases de efecto invernadoiro para identificar as opcións de mellora.

Segundo os principais resultados relatados neste estudo, a dieta atlántica pode considerarse beneficiosa non só desde o punto de vista sanitario, senón tamén desde a perspectiva ambiental debido ao importante consumo de produtos de orixe vexetal en comparación con outros patróns dietéticos máis ricos en produtos de orixe animal. Ademais, as características da dieta Atlántica, baseada na promoción do consumo de produtos de tempada, frescos e locais, cociña caseira e alimentos pouco procesados tamén contribúen á súa baixa pegada de carbono. En canto ás contribucións á pegada de carbono, a etapa de produción de alimentos é a principal responsable das emisións de gases de efecto invernadoiro, seguida da etapa de cocción e as actividades de transporte. A carne, os lácteos e os produtos do mar teñen a maior pegada individual, especialmente o queixo e a carne de tenreira, aínda que as súas cantidades consumidas non son tan importantes como outros alimentos como verduras ou froitas, que se consideran alimentos básicos na dieta atlántica recomendada. En canto á calidade nutricional, deberían promoverse as dietas diarias con maiores puntuacións de índice, xa que están vinculadas a unha menor inxestión de proteínas totais e produtos de orixe animal. A pegada de carbono total da dieta podería reducirse minimizando a inxesta de produtos de orixe animal de acordo con outros estudos. Así, aínda que as cantidades inxeridas de carne e produtos lácteos non son moi elevadas no patrón atlántico, aínda poderían reducirse, sendo compensadas pola inxesta de proteínas de orixe vexetal. É necesario analizar con máis detalle o aumento da calidade nutricional xunto coa mellora da pegada de carbono asociada ao cambio da inxesta proteica da orixe animal ao vexetal.

Capítulo 4: Vinculación da sustentabilidade ambiental e a calidade nutricional das recomendacións da dieta do Atlántico e os hábitos de consumo reais en Galicia (noroeste de España).

O presente capítulo enfócase desde a perspectiva de que os patróns de consumo alimentario reais normalmente non se atopan en liña coas recomendacións saudables. Polo tanto, o principal obxectivo deste capítulo é comparar, desde unha perspectiva de sostibilidade ambiental e calidade nutricional, as recomendacións da dieta Atlántica tradicional coas tendencias de consumo reais, considerando a Galicia como caso de estudo, así como dar resposta á pregunta se os patróns de consumo actuais aseguran un perfil nutricional óptimo. Finalmente, o nivel de concorrencia entre ambos patróns dietéticos tamén se determinou considerando tanto a pegada de carbono, a partir dun enfoque de avaliación do ciclo de vida asociado á produción de alimentos, como a calidade nutricional. Respecto a este último, utilizáronse dous índices diferentes para a análise para mellorar a solidez e a consistencia dos resultados: o Nutrient RichDiet 9.3 e o Health Score.

Así pois, os resultados deste capítulo demostran que hai unha desviación entre os patróns de consumo reais e as dietas baseadas nas recomendacións de saúde, tanto desde o punto de vista ambiental como nutricional. Deste xeito, no caso concreto de Galicia, o patrón dietético actual obtén puntuacións moito máis baixas nos índices nutricionais e unha pegada de carbono mais elevada que as da dieta Atlántica tradicional. Polo tanto, un cambio nas tendencias actuais de consumo de alimentos cara ás recomendacións da pirámide atlántica sería beneficioso. Neste sentido, como puntos débiles na dieta galega (inxestión excesiva de sodio), os alimentos procesados e precociñados deberían deixarse de lado, xa que son os de peor calidade nutricional. Non obstante, tamén se comprobou que tanto a calidade nutricional como a ambiental dos dous escenarios estudados poden mellorarse substituíndo a carne por unha fonte de proteína máis sostible, tomando como referencia a metodoloxía empregada neste estudo. Neste contexto, é recomendable proporcionar máis proteínas de orixe vexetal que as de orixe animal, sendo as leguminosas o mellor substituto posible.

Capítulo 5: Avaliando a dieta portuguesa na procura dun patrón de consumo con menos pegada de carbono e máis saudable.

Como se mencionou anteriormente, os patróns de consumo actuais desvíanse cada vez máis das recomendacións, polo que se occidentalizan e inclúen o consumo de cantidades significativas de produtos procesados e ultra-procesados e unha gran cantidade de produtos de orixe animal. No caso de Portugal, as dietas Mediterránea e Atlántica coexistiron tradicionalmente no país, pero é previsible que os patróns de consumo actuais non se axusten a eles. En consecuencia, os principais obxectivos do capítulo 5 son medir o impacto ambiental e a calidade nutricional do patrón dietético portugués e propoñer os cambios necesarios para facer a dieta máis sostible. Seguindo o mesmo enfoque que nos Capítulos 3 e 4, o impacto ambiental dos patróns dietéticos determínase en función da pegada de carbono, considerando unha perspectiva de avaliación do ciclo de vida. En consecuencia, a calidade nutricional avalíase estimando o Nutrient Rich diet 9.3, aínda que tamén se leva a cabo unha discusión sobre puntuacións alternativas. Finalmente, a proposta dunha dieta alternativa realízase seguindo as recomendacións da dieta de Saúde Planetaria da Comisión EAT-Lancet, coa intención de acadar a desexada mellora na pegada de carbono e na calidade nutricional da dieta portuguesa.

Como resultado, identificouse unha pegada de carbono considerablemente alta en comparación coa das dietas recomendadas. Non obstante, pódese asimilar aos patróns de consumo reais avaliados noutros países. Polo tanto, a pegada de carbono notablemente alta pode asociarse ao alto consumo de enerxía e produtos gandeiros. Finalmente, tendo en conta a baixa calidade nutricional e a alta pegada de carbono e a inxestión calórica da dieta portuguesa, deseñouse un exemplo dunha dieta máis sostible, atendendo ás directrices da dieta de Saúde Planetaria da Comisión EAT-Lancet. Deste xeito, as cantidades de certos produtos alimenticios (é dicir, carne, grans e graxas) reducíronse e substituíronse por outros máis saudables e máis respectuosos co medio ambiente (é dicir, froitas, verduras, legumes e froitos secos). Como resultado, reduciuse a FC e aumentou de xeito moi significativo a calidade nutricional, con valores máis próximos aos recomendados. En resumo, deberían tomarse medidas para mellorar a calidade nutricional e reducir tanto a inxestión de enerxía como a pegada de carbono, para lograr un estilo de vida máis saudable e respectuoso co medio ambiente para a poboación portuguesa.

A terceira sección da tese titúlase "Hábitos dietéticos españois" e consta de tres capítulos. En consecuencia, a investigación neste caso céntrase na análise dos patróns de consumo de alimentos españois, desde unha perspectiva multidisciplinar e multicriterio. Así, entre os Capítulos 6 e 8 avalíase a sustentabilidade de diferentes patróns dietéticos, considerando as variables ambientais, nutricionais e socioeconómicas como se mencionou anteriormente. A información contida nestes capítulos, así como os principais resultados explícanse a continuación.

Capítulo 6: Perfil ambiental e nutricional dos patróns de consumo de alimentos nas distintas zonas climáticas de España.

Aínda que a globalización do sector alimentario impón patróns de consumo similares, tamén é evidente que os hábitos alimentarios e a súa calidade están influenciados por un gran número de variables culturais, ambientais, socioeconómicas e tecnolóxicas. Neste sentido, España é un país cunha gran diversidade de culturas e estilos de vida. Ademais, a pesar de ser un país relativamente pequeno en extensión, a variabilidade do clima é notable. Tendo en conta estas flutuacións, o principal obxectivo deste capítulo é identificar as variacións nos patróns de consumo de alimentos en termos de emisións de gases de efecto invernadoiro e inxestión de nutrientes. Neste marco, a información subministrada polo Ministerio de Agricultura, Pesca e Alimentación mediante a Unidade de Consumo, Comercialización e Distribución de Alimentos proporciona datos de consumo de alimentos da cesta da compra española. En concreto, e segundo as 5 áreas xeográficas principais, é posible consultar o Programa de Base de Datos de Fogares para identificar o consumo diario per cápita e así cuantificar os impactos ambientais asociados aos patróns alimentarios e o perfil nutricional do cidadán medio desas rexións obxectivo.

En función dos resultados, as emisións de gases de efecto invernadoiro e a adecuación nutricional difiren segundo as zonas. Neste sentido, as rexións máis frías situadas no norte do país están relacionadas co aumento da pegada de carbono debido principalmente a un maior consumo de produtos gandeiros e un maior consumo de enerxía. En termos de adecuación nutricional, as zonas do norte obteñen as mellores puntuacións derivadas dunha dieta máis equilibrada que inclúe un maior consumo de froitas, verduras, mariscos e aceite de oliva en comparación co resto das zonas. En canto aos produtos gandeiros, que son os que teñen maiores impactos ambientais (concretamente a carne vermella), podería ser interesante desenvolver novas políticas destinadas a reducir o seu consumo e ao mesmo tempo promover un consumo moderado dos producidos de xeito máis sostible.

Capítulo 7: Avaliación da eficiencia das dietas nas comunidades autónomas españolas: Un enfoque multicriterio transversal.

Lograr a adherencia a dietas sostibles é, por natureza, un desafío multidimensional e multicriterio. A medición da sustentabilidade debe ter en conta aspectos nutricionais, ambientais e socioeconómicos para garantir o benestar e a calidade de vida sen aumentar os impactos sobre o medio ambiente. Ademais, esta medición é especialmente relevante cando se observa unha alta variabilidade dos patróns alimentarios, incluso entre rexións do mesmo país. Esta investigación ten como obxectivo enriquecer a literatura actual sobre avaliación da sustentabilidade das dietas desenvolvendo e aplicando un marco metodolóxico para a avaliación da eficiencia dos patróns dietéticos baixo múltiples criterios transversais. En particular, os patróns dietéticos españois de 2016 considéranse caso de estudo para comprobar a viabilidade da metodoloxía. Para iso, as comunidades autónomas españolas son analizadas e comparadas tendo en conta criterios nutricionais, ambientais e socioeconómicos.

Para interpretar de forma combinada estes múltiples criterios transversais, o uso combinado da Análise por Envolvemento de Datos dentro do marco metodolóxico proposto neste traballo demostrou ser factible e valioso para a avaliación da eficiencia da sustentabilidade dos hábitos dietéticos. A aplicación deste marco metodolóxico ao estudo de casos de patróns dietéticos en España permitiu identificar sete rexións cos patróns dietéticos máis axeitados segundo os criterios de sustentabilidade seleccionados. De feito, todas as comunidades autónomas españolas, agás unha, presentaron puntuacións de eficiencia multicriterio superiores a 0,60, o que conclúe a presenza de hábitos dietéticos relativamente bos en España. En xeral, máis alá do estudo de caso de España, a metodoloxía proposta podería contribuír a definir pautas e políticas sólidas baseadas no desempeño de rexións con patróns dietéticos eficientes (é dicir, sostibles).

Capítulo 8: Podería a crise económica explicar a redución da pegada de carbono da alimentación? Evidencias de España na última década.

Como se mencionou no capítulo 6, os patróns dietéticos están influenciados por numerosos factores externos como o gusto e os costumes culturais, os aspectos nutricionais e económicos e as preferencias do estilo de vida e dos consumidores. Se non, os alimentos tamén causan un grande impacto sobre o medio ambiente e pode haber unha gran diferenza entre a elección de certos alimentos, como os vexetais ou os de orixe animal. Polo tanto, o principal obxectivo do presente capítulo é facer un seguimento do patrón de consumo de alimentos a nivel dos fogares durante un período de 10 anos (2008-2017), seleccionando España como caso de estudo. Este período considérase interesante xa que inclúe os anos máis duros da última crise económica, na que o país se viu gravemente afectado. Dito isto, a motivación do estudo é, polo tanto, a posible relación entre a crise económica e o impacto ambiental dun patrón de consumo de alimentos, que pode achegar coñecemento a un campo que non se estudou ata agora. Téñense en conta tanto os impactos que os produtos alimenticios provocan no medio ambiente (pegada de carbono) como as variables socioeconómicas que inflúen na elección do consumidor.

Segundo as principais conclusións deste capítulo, unha diminución da pegada de carbono non sempre é sinónimo dunha dieta máis saudable, xa que, aínda que o consumo de produtos animais diminúe co paso dos anos, tamén o fai dalgúns alimentos esenciais para unha dieta equilibrada e sa como froitas, verduras ou aceite de oliva; pola contra, tamén hai un aumento no consumo de comidas preparadas e alimentos procesados. Esta tendencia afasta os hábitos alimentarios das recomendacións tradicionais, o que pode ser máis pronunciado para os grupos de poboación máis vulnerables cun aumento da taxa de risco de pobreza e a dificultade para acceder a alimentos saudables. Se non, tamén se pode comprender os resultados que a poboación española aínda está lonxe de ser consciente dos impactos ambientais derivados dos alimentos, tendo en conta a gran cantidade de produtos de orixe animal que aínda hoxe forman parte do patrón dietético.

A Sección IV está composta polo Capítulo 9 e leva por título “Cadea de subministración de alimentos”. Despois de estudar diferentes patróns de consumo de alimentos, esta sección céntrase na avaliación detallada dos impactos ambientais que os alimentos que compoñen unha dieta poden ter sobre o medio ambiente, tomando como caso de estudo dous produtos relevantes como o aguacate e o espárrago verde. Esta investigación incluíuse na presente tese doutoral atendendo a varios motivos relevantes. Como se mencionou anteriormente, os patróns de consumo de alimentos dependen dunha ampla gama de cadeas de subministración complexas que varían constantemente, polo que é moi importante comprender o perfil ambiental de todos os produtos alimenticios incluídos nos patróns alimentarios humanos para realizar a modificación necesaria cara a dietas máis sostibles. A información contida neste capítulo, así como os principais resultados explícanse a continuación.

Capítulo 9. Pegada ambiental de produtos agro-exportados críticos na costa hiperárida peruana: un caso de estudo para aguacate e espárragos verdes.

Perú converteuse nun dos principais centros agrícolas do mundo para unha ampla gama de froitas e verduras. Dous destes produtos, o aguacate e o espárrago verde, chamaron a atención nos últimos anos no panorama internacional debido ao alto consumo de auga que requiren. Polo tanto, o principal obxectivo deste capítulo é estimar os impactos ambientais relacionados coa produción e exportación de dous produtos agroalimentarios peruanos amplamente exportados: aguacate (*Persea americana*) e espárragos verdes (*Asparagus officinalis*). A avaliación centrouse nos dous principais ámbitos de interese reportados polos produtores locais: a pegada de carbono e a pegada de auga desde a perspectiva do ciclo de vida, tendo en conta a importancia das emisións de gases de efecto invernadoiro na produción de alimentos, pero tamén o alto estrés hídrico e as condicións de degradación na rexión. de interese.

Os resultados do capítulo actual permitiron identificar os principais hotspots ambientais destes produtos a través dunha pegada ambiental utilizando avaliación do ciclo de vida. En liña con estudos previos sobre froitas e verduras, os produtos avaliados non presentaron alta intensidade de carbono na súa etapa de cultivo. Pola contra, en termos de pegada hídrica, os resultados mostran que son necesarias cantidades importantes de auga superficial e subterránea para satisfacer as necesidades destes cultivos perennes. Ademais, os resultados presentados neste capítulo permiten cubrir un importante baleiro de datos na literatura de avaliación ambiental en relación a dous produtos que foron moi discutidos dadas as súas demandas de auga. Aínda que se poden implementar accións de mellora específicas para mitigar estes impactos en función dos resultados proporcionados, son necesarios máis estudos que avalíen a saúde xeral dos acuíferos costeiros en Perú para comprender os riscos relacionados coa diminución dos niveis de auga e as súas consecuencias.

Finalmente, a Sección V consta do **Capítulo 10** que leva por título "Resultados xerais e conclusións da tese". Como o seu nome indica, esta sección recolle os principais resultados obtidos dos lagos do documento á vez que enumera perspectivas futuras para a adopción dun sistema alimentario máis sostible. Así, os patróns actuais de consumo de alimentos cara a outros máis saudables baseados principalmente na inxestión de produtos de orixe vexetal son unha das ferramentas máis poderosas para combater o cambio climático, xunto con outras pedras angulares como as melloras tecnolóxicas ou a redución da perda e o desperdicio de alimentos. Ao mesmo tempo, a consecución destas dietas tamén representa unha gran oportunidade para mellorar a calidade e seguridade alimentaria mundial, xa que garantirían unha nutrición adecuada e evitarían millóns de casos de desnutrición, enfermidades relacionadas coa alimentación e mortes prematuras. Neste contexto, as metodoloxías sobre a análise de impacto ambiental e nutricional aplicadas nesta tese demostráronse como útiles para este propósito, tamén en combinación con outros instrumentos complementarios para a integración de aspectos socioeconómicos.

Section I

Contextualization

CHAPTER 1

State of the art

SUMMARY

The planet is currently being pushed to the limits of its capacity, greatly exceeding the possibility of regeneration of natural resources. Global population growth, rising incomes and urbanization are joining forces to pose serious challenges to the food and agriculture systems, while the natural resources are often more limited to support such provision of services. As a result, the pressure on the different ecosystems is enormous and the environmental impacts caused on land, air, and sea are unprecedented. Among these burdens, climate change and its already present and increasingly unpredictable consequences must be highlighted. Thus, neat-zero GHG emissions objective must be achieved by 2050, while at the same time conserving and restoring biodiversity and minimizing pollution and waste.

Food system is one of the main contributors to climate change since it is responsible of about one third of the global GHG emissions from anthropogenic sources. Despite the great impact that food production has on the environment, it should be noted that those from animal-origin are responsible for most of these pressures. Furthermore, food quality and safety are also at serious risk worldwide, as every year millions of people are hungry, malnourished, suffer from severe diseases, or die as a result.

In this context, it is more urgent than ever to achieve a sustainable food system that is environmentally friendly, provides food safety and quality for the entire world population, and at the same time is socioeconomically acceptable. To this end, changes in current dietary patterns are one of the most powerful and effective tools. Adherence to traditional diets, which are mainly based on the consumption of plant-based products and limited consumption of animal-origin and ultra-processed foodstuffs, is considered as cornerstone for achieving this goal.

CHAPTER 1 - OUTLINE

1.1. ENVIRONMENTAL AND SOCIOECONOMIC CONTEXT

1.1.1. CURRENT PLANETARY SITUATION

Humanity is living beyond the means of Planet Earth and our use of finite resources continues to spiral upward, while GHG emissions continue to disperse into the atmosphere and the earth continues to heat up (Schaltegger, 2017). Therefore, it becomes clear that there is less and less time to act and implement the necessary actions (Haigh et al., 2021). Furthermore, following the global change caused by the COVID-19 pandemic, the world is more aware than ever that business-as-usual cannot continue (Pierrehumbert, 2019). Climate breakdown, resource scarcity, ecological collapse, among other many issues have moved from the medium and long-term to the now, as frequent shocks and crises have exposed the fragility of our current, linear system (Haigh et al., 2021). In this context, Global economic growth since mid-20th century has driven exponential human improvements, yet this has come at a huge cost to the stability of Earth's operating systems that sustain us (Otero et al., 2020; WWF, 2021). Humans are now overusing the biocapacity of the Earth by at least 56%, being the land-use change one of the biggest problems, due to where and how the food is produced (Otero et al., 2020). Furthermore, the oceans are also in the spotlight, due to overfishing, pollution, coastal development and climate change, causing a growing spectrum of adverse across marine ecosystems (WWF, 2021; Yan et al., 2021). Air pollution on the other hand is also a matter of great relevance since annually 8.7 million people die prematurely due to poor air quality (Hamanaka and Mutlu, 2018; Sicard et al., 2021; Vohra et al., 2021). The set of all these mentioned facts bring as final consequence a global destabilization that unleashes increasingly strong and unpredictable natural disasters that endanger human life as we know it today (Sawada and Takasaki, 2017). Therefore, this environmental changes are undermining hard-won development gains by causing economic costs and millions of premature deaths annually (Bakhsh et al., 2020; Sharma and Chowhan, 2020); and they are also impeding progress towards ending poverty and hunger, reducing inequalities and promoting sustainable economic growth, work for all and peaceful and inclusive societies (UNEP, 2021).

Besides this, the world population has been growing at exponential rate since the beginning of the 20th century and this trend has become extremely acute in the last decades of this century and up to the present (Dong et al., 2018). Thus, the world population reached 7.7 billion in mid-2019, having added one billion people since 2007 and two billion since 1994 (United Nations, 2019a). Thus, taking into account the current prospects, it is expected to reach 8.5 billion in 2030 and 9.7 billion in 2050. Additionally, nowadays we live in a more urban world, and the humanity is experiencing a significant shift to urban living within the last century, and more than half of the population is living in cities and their surroundings, and it is projected to increase to 68% by the year 2050. As a result, with a growing and more urban population, consumption and production patterns are far from being sustainable (United Nations, 2019b; Weber and Sciubba, 2019).

Human beings are currently living turning its back to the environment, not realizing that we are inherently dependent on it for survival (Gabrysch, 2018); it is for this reason that it is urgent to make peace with nature (UNEP, 2021). The well-being of present and future generations depends on an immediate and urgent break with the current trends of environmental decline and the coming decades are crucial for this. In this context, society have to reduce carbon dioxide emissions by 45% by 2030 compared to 2010 levels, and reach neat-zero emissions by 2050 to limit warming to 1.5 °C as aspired to in the Paris Agreement , while at the same time conserving and restoring biodiversity and minimizing pollution and waste (UNEP, 2021). To this end, economic, financial and productive systems should be transformed to lead and power the shift to sustainability, including natural capital in decision-making, eliminating environmentally harmful subsides and investing in the transition to a sustainable future.

1.1.2. Food production, environment and climate change

The food system is considered one of the most important issues of negative environmental impacts in the world (Alexander et al., 2017; Schmidt-Traub et al., 2018), mainly in terms of GHG emissions, water requirements and land use (Poore and Nemecek, 2018). In this sense, food accounts for over one third of global anthropogenic GHG emissions (i.e., 18 Gt CO_2 eq · year^{-1}) (Crippa et al., 2021); about 50% of the world's habitable land is used for agriculture; more than two thirds of global fresh water withdrawals are used for agriculture (Schmidt-Traub et al., 2018); and around 80% of ocean and freshwater eutrophication is also caused by the agri-food sector (Ritchie and Roser, 2020), and at the same time, this activity is the single largest cause of the world's biodiversity loss (Searchinger et al., 2019). Moreover, these impacts are expected to increase even more (between 50% and 90%), taking into account the aforementioned growth rate of the global population and in absence of adequate and firm measures (Springmann et al., 2018). Among the environmental impacts mentioned, it should be noted that the carbon footprint (CF) is one of the most important ones due to the great consequences it has on the environment and the social relevance that it has acquired in the last decades (Roibás et al., 2018).

Despite the great impact that food production has on the environment, it should be noted that those from animal-origin are responsible for most of these pressures (Tullo et al., 2019). For instance, combining pastures used for grazing with land used to grow crops for animal feed, livestock accounts for 77% of global farming land (Ritchie and Roser, 2020); while livestock uses most of the world's agricultural land (ca. 83%) and is responsible of about 60% of GHG from food system, it only produces 18% of the world's calories and 37% of total protein (Poore and Nemecek, 2018). Furthermore, animal-source food production is one of the most dynamic elements of the food system since livestock and aquaculture production has been increasing at an average rate of 2.46% and 5.79% per year respectively from 1993 to 2014 (FAO, 2021). It is for this reason that the selection of one type of food versus another entails direct consequences in the supply chain, as well as environmental, economic and social impacts associated with the production processes (Hilborn et al., 2018). In this sense, according to Hilborn et al. (2018), there are striking differences in terms of environmental impacts of different animal-origin foodstuffs production method and, depending upon which particular environmental issue is considered most important, the relative ranking of different production methods can vary greatly. However, despite this, plant-based foodstuffs are more environmentally friendly in comparison with animal-origin resources-intensive products such as livestock products (Rosi et al., 2017).

Given the great impact of the food system on the environment and especially on climate change, in recent years many studies have been carried out in this regard (Crippa et al., 2021; Poore and Nemecek, 2018; Springmann et al., 2018; Willett et al., 2019). For instance, a recent research from Crippa et al. (2021) evaluated the relative contribution of the food system to GHG emissions of all countries in the world, developing a new global emissions database; this database provides a complete and consistent data source in time and space of GHG emissions from the global food system, from production to consumption, including processing, transport and packaging. The main outcome of this study reveals those emissions from the food system in 2015 amount to 34% of the total GHG emissions on average in the world. However, this contribution varies largely depending on the region (e.g., from 20% in Russia to 67% in Africa). In this context, the largest contribution came from agriculture and land-use change activities (ca. 71%), with the remaining were from supply chain activities such as retail, transport or consumption. Another research carried out by Poore and Nemecek (2018) assessed the environmental impact of food production from a different perspective, collecting environmental data from 38,700 farms, and 1,600 processors, packaging types, and retailers. Thus, a global view of the environmental impacts of the entire food supply chain is provided and it is reported that these impacts can vary 50-fold among producers of the same product, creating consequently substantial mitigation opportunities. Finally, although the mitigation opportunities of producers are detected, the importance of the role of the consumer and dietary-changes to mitigate the impacts is also highlighted. Otherwise, the study carried out by Springmann et al. (2018) determines the options for keeping the food system within the environmental limits, considering that by the year 2050 the environmental effects of food production could increase by 50-90% in the absence of technological changes and dedicated mitigation measures. Three main options are studied as they are dietary changes towards healthier and more plant-based diets, improvement in technologies and management, and reduction of food loss and waste. However, according to the results, no single measure is enough to keep the environmental impacts within planetary boundaries and it is concluded that a synergistic combination of them is needed to sufficient mitigate the estimated increase in the pressures over the environment. Finally, Willett et al. (2019) delved into the enormous effect of changes in dietary patterns in reducing the environmental impacts of the food system, and quantitatively describe a universal healthy reference diet to provide a basis for estimating the health and environmental effects of adopting an alternative diet; this healthy reference diet largely consists of vegetables, fruits, whole grains, legumes, nuts, and unsaturated oils, while including low to moderate consumption of animal-based products, and no or low quantity of red meat, processed foods and added sugars. At the same time this diet is englobed in the framework of the so-called win-win diets, which are good both for the health and the environment.

1.1.3. FOOD SAFETY AND QUALITY

Ready access to safe and nutritious food is a basic human right (Fung et al., 2018); However, the most recent estimate for 2019 shows that prior to the COVID-19 pandemic, almost 690 million people, or 8.9% of the global population, were undernourished (FAO et al., 2020; Hirvonen et al., 2021). This estimation reveals that about an additional 60 million people have become affected by hunger since 2014, and if this trend continues, the number of undernourishment people will exceed 840 million by 2030. Furthermore, every year around the world, over 420,000 people die and some 600 million people (i.e., almost one in ten) fall ill after eating contaminated food; in fact, foodborne hazards are known to cause over 200 acute and chronic diseases from digestive tract infections to cancer (FAO, 2019). Hence, the world is not on track to achieve the zero-hunger objective, even without the negative effects that COVID-19 will likely have on hunger. In this sense, preliminary projections based on the latest available global economic outlooks suggest that the COVID-19 pandemic may add an additional 83 to 132 million people to the ranks of the undernourished (FAO et al., 2020; Gundersen et al., 2021).

These trends in food insecurity contribute to increasing the risk of child malnutrition, as food insecurity affects to diet quality, including the quality of children's and women's diets, and people's health in different ways (Drammeh et al., 2019; Paslakis et al., 2021). Thus, food insecurity can worsen diet quality and consequently increase the risk of various forms of malnutrition, potentially leading to undernutrition as well as overweight and obesity (FAO et al., 2020). In this context, price and affordability are key barriers to accessing sufficient, safe, nutritious food to meet dietary needs and food preferences for an active and healthy life (Crawford et al., 2017; Herforth et al., 2020). Previous literature has shown clearly that more nutritious foods and diets are more expensive (5 times on average) than staple products and energy dense diets (Headey and Alderman, 2019). For the poorest people, consequently, acquiring enough essential nutrients and nutritious food groups would consume a very large proportion of their total income or even exceed it. In these situations, affordability imposes an insurmountable obstacle, so price and income constraints would need to be addressed before nutrition knowledge and behavior change could be effective drivers of food choice (Herforth et al., 2020).

Otherwise, on the flip side approximately 2 billion people in the world are overweight or obesity, that is more than two and a half times the number of chronically undernourished people globally (GBD, 2017; Searchinger et al., 2019). Once considered a high-income country problem, the number of obese and overweight people is now rising in low and middle-income countries (Nardocci et al., 2019). According to current trends and in the absence of adequate measures, the figure could reach 3.1 billion by 2050. This worrying trend is mainly due to the rising consumption of ultra-processed foods of minimal nutritional value, such as sodas, instant noodles, and packaged sweet and salty snacks (Herforth et al., 2020; Pagliai et al., 2021). At the same time, the rise in consumption of these foods is partially based on the abundant supply and low prices of starchy staples, sugars and oils that constitute their main ingredients and make them relatively cheap, in addition to the marketing which promotes these products as aspirational foods compared to traditional, minimally processed foods (Herforth et al., 2020). Furthermore, there is also a correlation between the consumption of ultra-processed foods and changing lifestyles, time scarcity, and sociodemographic factors (Djupegot et al., 2017).

In light of these evidence, it is clear that food safety and quality of the current food system is not moving in the wright direction (Fung et al., 2018). To increase the affordability of healthy diets the price of nutritious food must come down. Tackling these costs will require large transformations in food systems with no one-size-fits-all solution and different trade-offs and synergies for countries (FAO, 2019; Mc Carthy et al., 2018). Therefore, countries will need a rebalancing of agricultural policies and incentives towards more nutrition-sensitive investment and policy actions throughout the entire supply chain to reduce food losses and increase efficiencies at all stages (FAO, 2019). Additionally, nutrition-sensitive social protection policies will also be central for them to increase the purchasing power and affordability of healthy diets of the most vulnerable populations (FAO et al., 2020). Policies that more generally foster behavioral change towards healthy diets will also be needed. Thus, collective stakeholder engagement will prove essential in bringing about the policy changes and investment reforms required to achieve a solution (Mc Carthy et al., 2018).

1.1.4. HEALTH EFFECTS OF DIETS

Human diets are more than the sum of individual food items. They are complex combinations of different food ingredients, influenced by cultural and regional preferences (De Ruiter et al., 2014). The relevance of the link between diet, longevity, and health is well known and has been studied for several decades (Amine et al., 2003; Popkin Barry et al., 2001; Satija and Hu, 2018). Moreover, this issue is gaining special importance in the las years due to the rising society concern about the direct relation between diet and non-communicable diseases (NCDs) such as obesity, cardiovascular diseases, diabetes, and certain types of cancer (Afshin et al., 2017; Estruch et al., 2018). Moreover, diet not only affects the state of health but also several studies have reported the unequivocal link between nutrition and mental health (Adan et al., 2019; Owen and Corfe, 2017). For instance, increased consumption of fresh fruits and vegetables is associated with increased reported happiness and higher levels of mental health and well-being (Adan et al., 2019). In addition, poor diet combined with risky behaviors such as smoking or physical inactivity can further aggravate the problems resulting from all these parameters (Vallance et al., 2018).

One of the most relevant research in the literature regarding this issue was performed by Afshin et al. (2017), and it studies the health effects of dietary risks in 195 countries between 1990 and 2017. According to the results, in 2017, 11 million deaths and 255 million disability-adjusted life-years (DALYs) were attributed to dietary risk factors. In this context, high intake of sodium is the leading cause of mortality attributed to poor diet, followed by low intake of whole grains, and low intake of fruits, vegetables, nuts, and seeds. These findings display that suboptimal diets are responsible for more deaths than any other risk globally, including tobacco smoking, highlighting the urgent need for improving human diets across the nations (Afshin et al., 2017). In light of these results, it is suggested that dietary policies focusing on promoting the intake of components of diet for which current intake is less than the optimal level might have a greater effect than policies only targeting sugar and fat intake reduction.

1.2. TOWARDS A MORE SUSTAINABLE FOOD SYSTEM

According to FAO, "Food systems encompass the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products that originate from agriculture, forestry or fisheries, and parts of the broader economic, societal and natural environments in which they are embedded" (FAO, 2018). At the same time, food system is composed of subsystems (e.g., farming system, waste management system, input supply system), and interacts with other key systems such as energy system, trade system, health system (Herrero et al., 2020). Otherwise, a sustainable food system is a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised (FAO, 2018). Accordingly, it encompasses that it is It is profitable throughout (economic sustainability), it has broad-based benefits for society (social sustainability), and it has a positive or neutral impact on the natural environment (environmental sustainability). As displayed in Figure 1.1, the interplay between economic, social and environmental sustainability inherently entails eco-social progress, and green and inclusive growth.

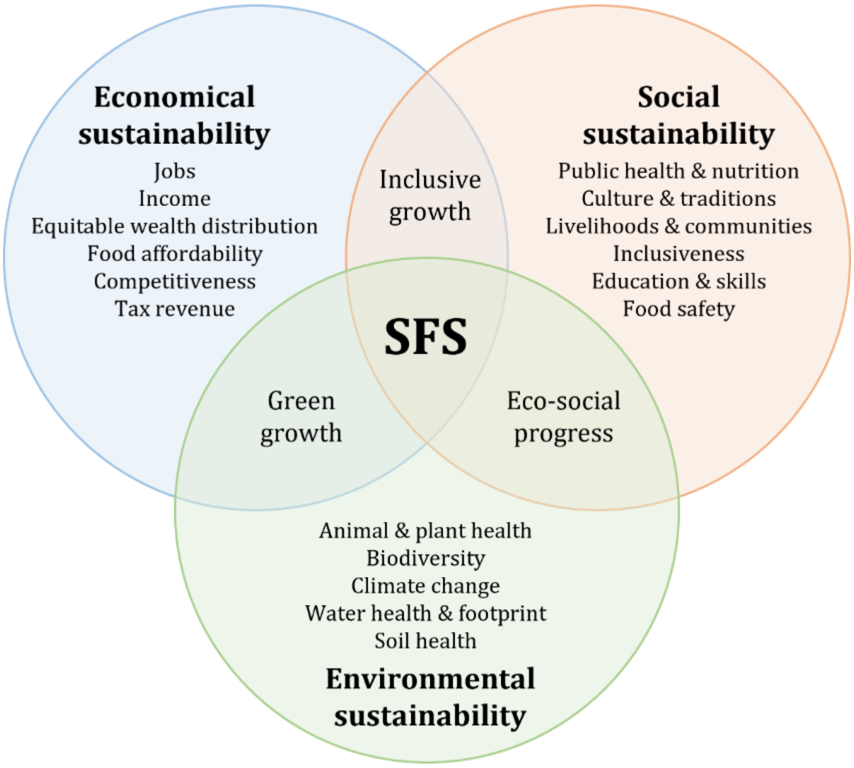

Figure 1.1. Representation of the dimensions of a sustainable food system (SFS). Adapted from European Commission (2020).

Sustainable food systems must be considered in the context of rapid population growth, urbanization, growing wealth, changing consumption patterns, globalization, climate change, and the depletion of natural resources. This is why they are fundamental to ensuring that future generations are food secure and eat healthy diets (FAO and INRAE, 2020). There is a large body of scientific evidence and policy-relevant recommendations on what would contribute to a sustainable food system (European Commission, 2021; Fan et al., 2021; Laso et al., 2018; SAM, 2019). Although there are different approaches about the exact type of actions to be taken, there is a wide consensus that synergistic combination of policies and action is required (Herrero et al., 2020; SAM, 2019). Therefore, these actions should be focused on the following efforts (European Commission, 2020):

i. To promote sustainable intensification and/or scale-up agro-ecological approaches, increasing or maintaining yields and efficiency while reducing environmental pressures.

ii. To reduce food loss and waste, while encouraging the reuse and recycling of unavoidable food waste.

iii. To make dietary changes towards healthier and more plant-based (i.e., less resource intensive) diets.

iv. To improve the resilience and robustness of the food system in particular by diversification, primarily to adapt to the effects of climate change.

v. To increase the responsibility and stewardship of producers and consumers on the environmental, economic, social and public health effects of the food system through increased participatory policy

Having said this, the transformation towards a sustainable food system requires the adoption of a multitude of measures in various fields such as environment, economy and society to increase its resilience to future adverse events or shocks such as the recent COVID-19 pandemic (Fan et al., 2021). Therefore, even though there is not a universal agreed definition of what a sustainable system is, a broad agreement exists on what the outcomes of a sustainable food system should be.

1.2.1. Sustainable Development Goals

The Sustainable Development Goals (SDGs) are a call to action for all countries, poor rich and middle-income, to promote prosperity while protecting the planet (United Nations, 2019b). They recognize that ending poverty must go hand in hand with strategies that foster economic growth and address a variety of social needs, including education, health, social protection and job opportunities, while addressing change climate and environmental protection. More important than ever, the goals also provide a critical framework for COVID-19 pandemic recovery. Figure 1.2. displays the 17 SDGs included in the 2030 Agenda for Sustainable Development of the United Nations.

Figure 1.2. Sustainable Development Goals included in the 2030 Agenda for Sustainable Development of the United Nations. Source: adaptation from United Nations.

Sustainable food systems do not just help to end hunger, but also, they can help the world achieve critical progress on all 17 Sustainable Development Goals (United Nations, 2021). In this context, according to United Nations, the grade in which sustainable food system can help in the achievement of each SDG is mentioned below: More than 700 million people, (ca. about 10% of the world population), still live in extreme poverty; sustainable food systems can contribute to the fight against poverty by creating good jobs, improving access to food, and supporting healthy communities (SDG1) (United Nations, 2021). Near 700 billion people were malnourished by the end of 2019 and without rapid intervention, the COVID-19 pandemic could force an additional 130 million people into chronic hunger; rebuilding our food system towards a more sustainable, productive and resilience one, is essential for solving long-term hunger and managing acute crises, like diseases outbreaks and extreme climate events (SDG2). Poor nutrition causes almost 50% of deaths in children under five (ca. 3.1 million children each year), and a sustainable food system supports therefore adequate nutrition, which helps people of all ages to achieve good health (SDG3). Sustainable food systems can enable all near 369 million children dependent on school meals to have a healthy and balanced diet, which is critical to success in school (SDG4). Women produce between 60% and 80% of food in most developing countries and are responsible of about half of the global food production; sustainable food systems can empower and support women and strengthen their livelihoods around the world (SDG5) (United Nations, 2021).

Water scarcity affects more than 40% of global population and it is expected to increase; a sustainable food system can ensure the sustainable use of this precious resource, while reducing the pollution in our natural water systems (SDG6) (United Nations, 2021). The energy sector is the single largest contributor to global GHG emissions, and a sustainable food system maximizes the use of clean and renewable energy sources, reducing consequently the impact of the food sector (SDG7). Agriculture is the single largest employer worldwide, providing livelihoods for 40% of the global population; a sustainable food system can create decent jobs and support the incomes of billions of people around the world (SDG8). Recent innovations in climate-smart agriculture have shown that food production can generate environmental benefits, as well as social and economic benefits (SDG9)(United Nations, 2021). About 1.5 billion people live in households supported by small farms; many of those households are extremely poor and sustainable food systems can help some of the poorest of the poor by providing decent work, good income and a healthy and balanced diet (SDG10). More than half of the world's population is living in cities; a sustainable food system helps to ensure that city dwellers everywhere and especially the urban poor who have limited purchasing power, are adequately nourished (SDG11). One third of all food produced ends up rotting in consumer and retail bins or spoiling due to poor transportation and collection practices; sustainable food systems reduce waste and spoilage and enable consumers to make smart choices in their food purchases (SDG12). Agriculture directly accounts for about 17% of total GHG; sustainable food systems can reduce this impact by reducing emissions of critical climate-warming gases, including methane and carbon dioxide (SDG13) (United Nations, 2021).

Oceans are the world's largest source of protein, with more than 3 billion people depending on the oceans as their main source of protein; sustainable food systems can ensure the long-term viability of global fisheries while protecting the health of the ecosystems that host them (SDG14). About 80% of the human diets are made of plant-based products; sustainable agriculture can reduce deforestation and support healthy terrestrial ecosystems, while providing a vital livelihood for people around the world (SDG15). Almost 80% of the 155 million stunted children in the world live in countries affected by violent conflict; sustainable food systems can reduce the critical stresses faced by families, communities and nations around the world, paving the way for peace and building strong institutions (SDG16). The total amount of development assistance around the world has shown an upward trend since at least the beginning of the 21st century. At the same time, we have seen a proliferation of coalitions, multi-stakeholder partnerships, and South-South cooperation. A renewed focus on sustainable food systems can drive this progress, while delivering tangible benefits to people and communities around the world (SDG17) (United Nations, 2021).

1.2.2. Sustainable diets

Two of the major challenges of our times are malnutrition in all its forms and the degradation of environmental and natural resources, as mentioned in previous sections. One of the most important action for the adoption of a sustainable food system is the transformation of current food consumption patterns towards more sustainable and less resource-intensive ones (See section 1.1.2.) (Meybeck and Gitz, 2017). According to FAO and WHO, sustainable healthy diets are "dietary patterns that promote all dimensions of individuals' health and wellbeing; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable". (FAO and WHO, 2019). Health and environmental sustainability are inextricably linked in this type of diets, which is why the EAT-Lancet commission introduces the win-win diet framework (i.e., good for the health and the environment) (Willett et al., 2019). In this context, the aims of sustainable healthy diets are to achieve optimal growth and development of all individuals and support functioning and physical, mental, and social wellbeing at all life stages for present and future generations. contribute to preventing all forms of malnutrition (i.e., undernutrition, micronutrient deficiency, overweight and obesity); reduce the risk of diet-related NCDs; and support the preservation of biodiversity and planetary health (FAO and WHO, 2019). Ultimately, sustainable healthy diets must combine all the dimensions of the sustainability concept, including additionally the pillar of health (i.e., environment-health-socioeconomic).

Nowadays, there are several consolidated and widely recognized examples of sustainable diets such as the Mediterranean diet, the Atlantic diet or the Planetary health diet proposed by the EAT-Lancet commission (Castañé and Antón, 2017; Esteve-Llorens et al., 2019a; Willett et al., 2019). These three sustainable dietary patterns are explained in detail below.

1.2.2.1. MEDITERRANEAN DIET

The Mediterranean diet involves a set of skills, knowledge, and traditions concerning crops, harvesting, fishing, animal husbandry, conservation, processing, cooking, and particularly the sharing and consumption of the products (UNESCO, 2010). It is for this reason, in addition to the multiple health benefits of adherence to this diet, that it has been recognized as Intangible Heritage of Humanity by the UNESCO (Moro, 2016; Saulle and La Torre, 2010). The Mediterranean diet is characterized by several aspects that can be summarized in the form of a decalogue (Fundación Dieta Mediterránea, 2021): The use of olive oil (rich in monounsaturated fatty acids) as the main source of fat; high consumption of fruits, vegetables, seeds and nuts; bread and other grain products such as pasta, rice and whole grains should be a part of the daily diet; all the consumed foodstuffs are preferred to be minimal processed, fresh and locally produced; consumption of dairy products on a daily basis; moderate consumption of fish, eggs and poultry; limited consumption of red and processed meats; sweets, cakes, and dairy desserts should be consumed only occasionally; water is the main beverage in the daily diet; and physical activity is considered just as important as eating well.

All these features make this dietary patterns very healthy, preventing therefore a wide variety of diseases (Estruch et al., 2018). For instance, in observational cohort studies, increasing adherence to the Mediterranean diet has been consistently associated with lower mortality risk and lower incidence of cardiometabolic diseases such as coronary heart disease, diabetes and obesity (Estruch et al., 2018; Trichopoulou et al., 2014). The key components of the Mediterranean diet are also beneficial for weight loss in obese people, and for the prevention of long-term weight-gain in non-obese population (Estruch et al., 2018). At the same time, in addition to being a dietary pattern with plenty of health benefits, the Mediterranean has been widely assessed from an environmental point of view, and there is unanimity in all the researches concluding that it is sustainable in this aspect as well (Blas et al., 2019; Castañé and Antón, 2017; Chai et al., 2019; Dernini et al., 2017; Fresán et al., 2018; González-García et al., 2020a; Grosso et al., 2020). In this context, these studies evaluated the environmental impact of the dietary pattern by means of different indicators such as CF, Water Footprint (WF), or land use, concluding that it is one of the diets with the lowest environmental impact.

1.2.2.2. ATLANTIC DIET

The Atlantic diet is another example of sustainable diet, which coexists with the Mediterranean diet in the Iberian Peninsula. Specifically, the traditional Atlantic diet is located in the Northwest of the Iberian peninsula, covering the territories of the autonomous region of Galicia and the north of Portugal (Leis Trabazo et al., 2019; Vaz

Velho et al., 2016). Its two main pillars in this case are the quality and diversity of local and seasonal products and a simple and healthy preparation. In relation to the quantities and proportions of food consumed, it is very similar to the Mediterranean diet, but nevertheless, it has several characteristics that distinguish it from the latter. Therefore, the traditional Atlantic diet is characterized by a high intake of seasonal foods, locally fresh and minimally processed; high consumption of vegetables, fruits, potatoes, bread and cereals, whole nuts and legumes; the use of olive oil for seasoning and cooking; High consumption of fish, mollusks and crustaceans; moderate ingestion of dairy products and meat (specially pork and beef meat); additionally, it prioritizes simple cooking methods, such as boiling, stewing, roasting and grilling, in order to keep the maximum nutritional properties of the food (Tojo and Leis, 2009).

Combining this traditional dietary pattern with a healthy lifestyle and regular physical activity has proven to have abundant health benefits. Accordingly, the Atlantic diet is considered a reference for a healthy diet associated with a lower risk of heart attacks among other health benefits involving reductions in total cholesterol and triglycerides as well as lower both obesity indexes and pulse wave velocity values (Calvo-Malvar et al., 2016; Rodríguez-Martín et al., 2019). Moreover, in addition to be good for the health, it is also environmentally friendly, since several studies proven its low environmental impact through different indicators such as carbon and water footprint (Esteve-Llorens et al., 2019b; González-García et al., 2020b).

1.2.2.3. Planetary health diet

The Planetary health diet is a novel diet proposal that was designed by the EAT-Lancet commission in 2018 (Béné et al., 2020; Willett et al., 2018). The EAT-Lancet commission brings together world-leading researchers as it is made up of 19 commissioners and 18 co-authors from 16 countries in various fields, including human health, agriculture, political science and environmental sustainability. In this context, the Planetary health diet arises from the challenge of providing 10 billion people with a sustainable healthy diet by the year 2050, and as have been mentioned in section 1.2, the adherence to this dietary patterns would be one of the cornerstones, among the many necessary to transform the current food system into a sustainable one (Cacau et al., 2021; Willett et al., 2018). In this case, it is not a traditional diet like the Mediterranean or Atlantic diets described above; however, it is generally based on the same principles, since it promotes primarily the consumption of plant-based foodstuffs, and limits as far as possible those products of animal origin. It has to be noted that this is the first attempt to set universal scientific targets for the food system that apply to all people and the planet (Willett et al., 2018).

Having said this, the Planetary health diet is based on the premise that transformation to healthy diets by 2050 will require substantial dietary shifts. Global consumption of fruits, vegetables, nuts and legumes will have to double, and consumption of foods such as red meat and sugar will have to be reduced by more than 50%. A diet rich in plant-based foods and with fewer animal source foods confers both improved health and environmental benefits. The plate should consist by volume of approximately half plate of vegetables and fruits; the other half, should consists of primarily whole grains, plant protein sources, unsaturated plant oils, and optionally, limited amounts of animal-sources proteins. Animal-origin products can therefore still continue to be present on our plates, but plant-based products need to be the main course. Additionally, it is also necessary to stay away from refined grains, high processed foods and added sugars. Following this recommendations, will low the risk of several types of cancers, strokes, and diabetes, helping to avoid about 11 million deaths per year worldwide, and several environmental degradation (Semba et al., 2020; Springmann et al., 2018).

An important consideration that has to be kept in mind is that although the Planetary health diet, which is based on health considerations, is consistent with many traditional eating patterns, it does not imply that the global population should eat exactly the same food, since it does not prescribe an exact diet. Instead, the Planetary health diet outlines empirical food groups and ranges of food intakes, which combined in a diet, would optimize human health. Local interpretation and adaptation of the universally-applicable planetary health diet is necessary and should reflect the culture, geography and demography of the population and individuals (Willett et al., 2018).

1.3. THESIS OUTLINE: OBJECTIVES AND STRUCTURE

The main objective of this doctoral thesis is the evaluation of the sustainability of different dietary patterns, from a multi-criteria perspective, taking into account both environmental and nutritional factors, as well as socioeconomic aspects. Additionally, the environmental impacts of the food production chain have been also evaluated from a life cycle approach through two case studies of relevant agricultural systems. With this in mind, the present document has been structured in five main sections with their respective chapters, as it is displayed in Figure 1.3.

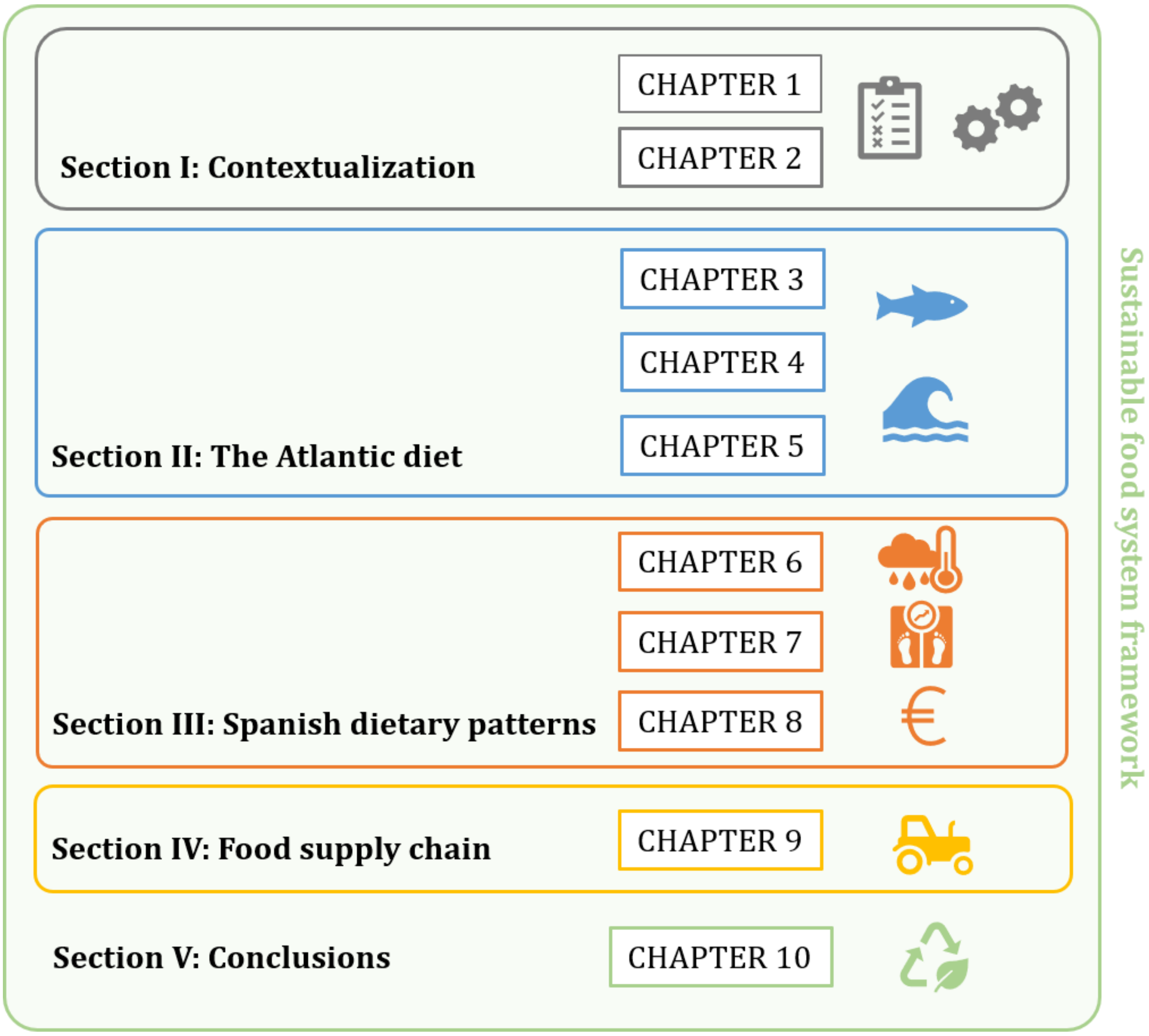

Figure 1.3. Graphical abstract of the thesis outline and structure

Section I: Contextualization. This section is aimed at providing potential readers with an overall vison of the state of the art of the problem to be addressed in this thesis as well as the methodological assessment tools used for this purpose. In this sense, **Chapter 1** is focused on the state of the art of the field studied, including the planetary environmental and socioeconomic context, the impact of consumption on different aspects, and the main variables to be included within a sustainable food system. **Chapter 2** presents the environmental and nutritional assessment tools used for the sustainability assessment of dietary patterns throughout this document, including Life Cycle Assessment (LCA) methodology, nutritional quality indexes, and Data Envelopment Analysis assessment tool.

Section II: The Atlantic diet. This section focuses on the study of the Atlantic diet and the current food consumption patterns related to its traditional geographical area such as northwestern Spain and northern Portugal. Therefore, in **Chapter 3**, the sustainability of the traditional Atlantic diet is evaluated from an environmental (i.e., CF) and nutritional point of view. Then, in **Chapter 4**, the Galician food consumption pattern is studied, also using environmental and nutritional variables, and comparing in this case the results with the traditional recommendations mentioned above. In third place, the sustainability of the Portuguese food consumption pattern is assessed in **Chapter 5,** and after verifying the deviations from the results of the traditional Atlantic diet, a series of improvements are proposed to obtain a dietary pattern that is more environmentally and health friendly, using the guidelines from the EAT-Lancet Planetary health diet.

Section III: Spanish dietary habits. In this section, dietary patterns at the country level of Spain are evaluated, from a multicriteria point of view, since in addition to the environmental and nutritional profile of the different food consumption patterns, other variables such socioeconomic aspects, climatic conditions or efficiency scores are considered. Thus, **Chapter 6** aimed at assessing the environmental and nutritional profile of food consumption patterns in the different climatic zones of Spain, that have been delimited considering the Köppen climate classification system for the Iberian Peninsula. Additionally, a novel sustainability index that couple GHG emissions and nutritional density has been estimated for the different consumption patterns. In second place, **Chapter 7** is focused on the efficiency assessment of diets in the Spanish autonomous regions, using a multi-criteria cross-cutting approach. Accordingly, Data Envelopment Analysis is used to obtain an efficiency score for each dietary pattern of the autonomous regions. Different variables such as CF, nutritional quality index, and socioeconomic aspects are considered to perform the analysis. As the last part of the section, **Chapter 8** focuses on the relationship between the CF of the average Spanish food consumption pattern and its variation throughout the period of economic crisis. A period of ten years is selected for this research (i.e., 2008-2017), and several tipping points are detected through the analysis of several socioeconomic variables.

Section IV: Food supply chain. After having studied different food consumption patterns, this section is focused on the detailed assessment of the environmental impacts that the foods that make up a diet can have on the environment, taking as a case study two relevant products such as avocado and green asparagus. For this purpose, **Chapter 9** evaluates from a LCA perspective the WF and CF of the production process of these products, allowing to identify hotspots and thus to suggest potential improvement actions to reduce as much as possible the pressures on the environment. This research has been included in the present doctoral thesis attending to several relevant reasons such as to understand the complexity of the food supply chain and the process of LCA, while contributing with novel information about strategic products to the literature.

Section V: Conclusions. Finally, **Chapter 10** summarizes all the general findings, results, and conclusions of the thesis.

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CHAPTER 2

Environmental and nutritional assessment tools

SUMMARY

Sustainable development is a priority issue for society and its institutions. In a context of continuous technological and socioeconomic development, together with population growth and the intensification of anthropogenic activities, new patterns of production and consumption need to be defined to make responsible behavior towards the environment and future generations a reality. Consequently, numerous methodologies have been developed in the last decades to bring together environmental protection, economic development, and social welfare. Similarly, in the context of food consumption, the concept of sustainable diet arises considering in this case the environmental, health and socioeconomic dimensions. The main objective of this chapter is therefore to provide an overview of the main methodological tools available for the environmental analysis and sustainability assessment of dietary patterns and agri-food products.

Especial attention has been paid to Life Cycle Assessment perspective for the evaluation of environmental impacts of diets and products, as it is a globally accepted and standardized methodology for this purpose. Furthermore, for the estimation of the nutritional quality several indexes have been selected as they are the Nutrient Rich index, the Nutrient Rich Diet 9.3, the Health Score, and the Sustainable Nutrient Rich Diet 3.3. Finally, the Data Envelopment Analysis method is also presented as a valuable tool for the integration of the three dimensions of a sustainable diet (environmental, health and socioeconomic) in form of a single efficiency value.

CHAPTER 2 - OUTLINE

2.1 OVERVIEW AND DEFINITIONS

The concept of sustainable development dates back to the Brundtland Report from several decades ago and it is defined as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs, integrating in this sense the economic development, environmental protection, and social participation (WCED, 1988). Despite the fact that this concept is more than two decades old, its importance has only grown throughout all this time and it continues to be one of the greatest challenges for humanity in the face of the climate emergency that we are facing (United Nations Environment Program, 2021). Furthermore, it can be applicable to any process or system, giving way to the concept of sustainable healthy diet. According to FAO and WHO, sustainable healthy diets are *dietary patterns that promote all dimensions of individuals' health and wellbeing; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable*. (FAO and WHO, 2019) (See Section 1.2.2.). Health and environmental sustainability are inextricably linked in this type of diets, which is why the EAT-Lancet commission introduces the win-win diet framework (i.e., good for the health and the environment) (Willett et al., 2019). In this context, the aims of sustainable healthy diets are to achieve optimal growth and development of all individuals and support functioning and physical, mental, and social wellbeing at all life stages for present and future generations. contribute to preventing all forms of malnutrition (i.e., undernutrition, micronutrient deficiency, overweight and obesity); reduce the risk of diet-related NCDs; and support the preservation of biodiversity and planetary health (FAO and WHO, 2019). Ultimately, sustainable healthy diets must combine all the dimensions of the sustainability concept, including additionally the pillar of health (i.e., environment-health-socioeconomic)

However, among the variables mentioned, it is of special interest to assess the environmental and nutritional impact of dietary patterns due to the well-known great relevance of their pressures on the environment and human health (Afshin et al., 2017; Springmann et al., 2018; Willett et al., 2019). Today's food supply chain is responsible of about one third of anthropogenic GHG emissions; food production is responsible of about 32% and 78% of global terrestrial acidification and eutrophication, respectively. All these emissions are the main contributors to the reduction of biodiversity and ecological resilience (Poore and Nemecek, 2018). Otherwise, low-quality diets, are responsible for more deaths that any other risk globally, including tobacco smoking (Afshin et al., 2017); accordingly, unhealthy diets are characterized by a high intake of sodium and a low ingestion of whole grains, fruits and vegetables, nuts and seeds, and omega-3.

Having said this, the main goal of the present doctoral thesis attempts to encompass all these aspects to evaluate the different dietary patterns. First, the environmental pillar is analyzed focusing especially on the carbon footprint under a life cycle approach; Secondly, the health pillar is addressed considering the assessment of the nutritional quality, which is estimated through the application of different indexes such as the

Nutrient Rich, the Nutrient Rich Diet 9.3, the Health Score, and the Sustainable Nutrients Rich Diet. Finally, different socioeconomic variables have also been considered with the intention of broadly completing the third dimension of a sustainable diet (socioeconomic pillar). Additionally, the Data Envelopment Analysis tool has been used to complement and integrate the mentioned variables in the form of an efficiency value (i.e., the better environmental, nutritional and socioeconomic performance, the better efficiency value).

2.2. Life cycle assessment methodology

Life Cycle Assessment (LCA) is a powerful and holistic tool to assess the environmental burdens throughout the production chain of a certain product or service. Its principles and guidelines are established in the International Standards ISO 14040 and 14044 (ISO, 2006a, b). The use of this methodology for the environmental profiling of both dietary patterns (Sara González-García et al., 2018) and food products (Heusala et al., 2020) has been recurrently used in recent years, so it is already widely established for this purpose. Thus, the fact that food consumption patterns depend on a wide range of constantly varying complex supply chain systems is important to understand the environmental profile of all the food products included in human diets in order to carry out the necessary modifications towards more sustainable diets. In fact, one of the strengths of the LCA methodology is its ability to estimate potential environmental impacts in a holistic manner (Hellweg and Milà i Canals, 2014), allowing the identification of environmental hotspots throughout the supply chain and trade-offs between impact categories and environmental areas of protection (ISO, 2006a). Accordingly, LCA can contribute to identifying opportunities to improve the environmental performance of products and processes, advising decision-makers, governments and administrations and consumers. ISO 14040 and 14044 standards stablish four main phases for the LCA as they are goal and scope definition, inventory analysis, impact assessment and interpretation (Figure 2.1).

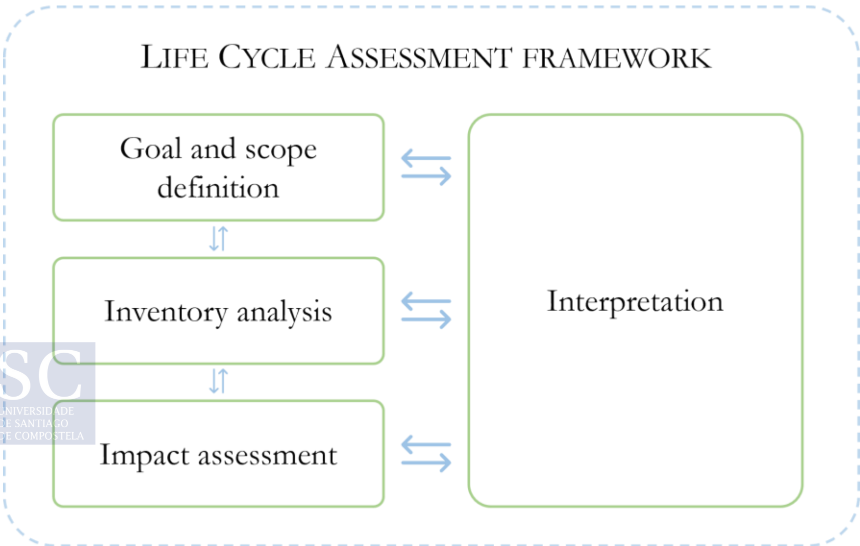

Figure 2.1. Phases of an LCA study (adapted from ISO 14040, 2006)

2.2.1. GOAL AND SCOPE DEFINITION:

It is the first phase of the LCA study and accordingly, the product or service to be analyzed should be defined together with the objectives to be achieved, as well as the intended audience and applications of the study. In this sense, the scope of the system is also established, including the system to be studied, its functions and functional unit (FU), the system boundaries and life cycle stages to be covered, the environmental impacts to be analyzed and the assessment methods, allocation procedures, data quality requirements, assumptions and limitations (ISO, 2006a).

- **Function and functional unit:** The system under study may have several possible functional units, and the one selected as the basis for the analysis will depend on the goal and scope considered. The FU can be defined as a measure of the performance of the functional outputs of the product system.

- **System boundaries:** The system boundaries determine the scope of the system studied. In general, all life cycle stages, unit processes and flows should be considered when establishing the system boundaries, including the raw materials acquisition, inputs and outputs in the main sequence processing, distribution, and transportation, fuel and energy requirements, recovery of used products, waste disposal and other additional operations. Nevertheless, sometimes the stages that are expected not to be significant can be cut-off to focus effort on obtaining more reliable data for the relevant processes.

- **Modelling approach:** two main alternatives of modelling are used in LCA: attributional, which is the most widely used, and consequential. The attributional approach refers to an actual supply chain of the product or service, along with its use and end-of life phases. Thus, it is assumed, that the system under study is integrated into a static technosphere, which makes it possible to estimate the potential environmental impacts of the system throughout its life cycle using average inventory data (Weidema et al., 2018). By contrast, the consequential model assesses the implication of the interaction of foreground system with other systems in the market, analyzing in this way a hypothetic supply chain in a dynamic technosphere that is reacting to its consequences (Weidema et al., 2019). In this context, only attributional approach is considered in this doctoral thesis.

2.2.2. LIFE CYCLE INVENTORY ANALYSIS

This phase mainly includes data collection, and calculation procedures for quantifying inputs and outputs relevant to the life cycle of the system to be assessed together with data on background processes. It is consequently the phase that requires the greatest efforts and resources in an LCA study, involving the collection and modelling of several flows, such as elementary flows, product flows and water flows. The Life Cycle Inventory has to be conducted according to the previously defined goal and scope, although it may be revisited after preliminary analysis (ISO, 2006a).

2.2.3. Life Cycle Impact Assessment

Life Cycle Impact Assessment aims at evaluating the significance of potential environmental impacts using results from the life cycle inventory analysis (ISO, 2006a). In general, this phase involves associating inventory data with impact indicators related to different dimensions such as human health, environment, and resource depletion. In this sense, the selection of impacts and methodologies used must be in concordance with the goal and scope defined. The three mandatory steps that has to include this evaluation are: Selection of impact categories and characterization methods, classification and characterization (ISO, 2006a, 2006b). Additional steps such as normalization, grouping and weighting can be performed optionally at a later stage.

2.2.3.1. Carbon footprint of dietary patterns

The evaluation of the environmental burdens derived from food consumption can be carried out through different impact categories such as carbon footprint, water footprint or land use (Blas et al., 2019; Castañé and Antón, 2017; S. González-García et al., 2018). However, the carbon footprint has been selected as the main indicator of the environmental impact from the dietary patterns evaluated in this thesis as will be seen in **Chapters 3** to **8**. In this context, the carbon footprint has gained recognition as an indicator focused on measuring the contribution of goods and services to climate change. It is defined as the term used to describe the amount of direct and indirect greenhouse gas (GHG) emissions emitted to the environment by a particular activity or entity in terms of kg of carbon dioxide equivalent (i.e., kg CO_2 eq) (ISO, 2013). Understanding these emissions, and where they come from, is necessary in order to reduce them especially considering the climatic emergency that we are facing and the huge potential that changes in dietary patterns have to reduce the GHG emissions (Willett et al., 2019).

2.2.4. Interpretation of the results

As last step, the interpretation phase carried out based on the combination of the main findings from the previous phases of the LCA study (ISO, 2006a). Additionally, this phase may incorporate sensitivity, consistency, and uncertainty analyses to ensure the reliability of the results. In this sense, these are expected to serve as basis for the conclusions and recommendations to decision-makers, in line with the goal and scope of the study.

2.3. Nutritional quality assessment

The evaluation of the nutritional quality of a dietary pattern is as important as its environmental or socio-economic impact to determine its sustainability according to FAO and WHO (2019), as mentioned above. In this context, different nutritional indexes have been selected for this purpose (see Figure 2.2.). The Nutrient Rich index is used in **Chapters 3** and **6**; the Nutrient Rich Diet 9.3 is applied in **Chapters 3, 4, 5,** and **7**; the Health Score is considered in **Chapters 4** and **5**; and the Sustainable Nutrient Rich Diet 3.3. is estimated in **Chapter 6.**

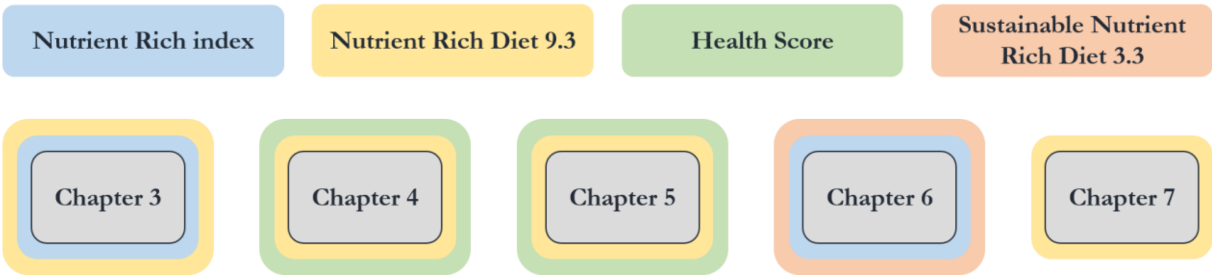

Figure 2.2. Overview of the indexes used to estimate nutritional quality of the dietary patterns in each chapter.

2.3.1. NUTRIENT RICH INDEX

The Nutrient Rich (NR) index is a formal scoring system that ranks foods based on their nutrient content, and it is used to estimate the variations in terms of nutritional quality between dietary patterns. Accordingly, it allows estimating the suitability of the intake of the most important micro and macronutrients. To this end, the NR index has been proposed for analysis (Van Kernebeek et al., 2014), which is a variation of the Nutrient Rich Food index defined by Drewnowski, (2009). This score considers a set of nutrients whose consumption should be increased and others that should be limited. Specifically, it considers protein, fiber, calcium, iron, magnesium, potassium, and vitamins C, D and E as qualifying nutrients; and saturated fats, sodium and total sugars as disqualifying ones (Van Kernebeek et al., 2014). Additionally, due to their remarkable importance as nutrients to boost (Röös et al., 2015; Van Dooren et al., 2017), plant-based protein (protein from plant-origin products such as fruits, vegetables, starch-based products, legumes and nuts), vitamin D, and essential fatty acids (EFA) are also considered for this doctoral thesis. Thus, the intake of qualifying and disqualifying nutrients has been quantified by dietary pattern, relating them to recommended daily values (RDVs) and maximum recommended values (MRV) for an adult woman, taken from Codex Alimentarius (FAO/WHO, 2017). To quantify nutrients intake (i.e., protein, plant-based protein, fiber, vitamin A, C, D and E, essential fatty acids, calcium, iron, potassium and magnesium), when exceeding 100% of their RDV, the latter value is fixed, since nutrient needs are considered to be met. Conversely, this it is not the case for the disqualifying nutrients (i.e., saturated fats, sodium, and total sugars), since their intake is not fixed to 100% of the MRV when it is exceeded, in order to check the excess percentage. As a result, the Nutrient Rich score is expressed as the percentage of ingested nutrient in relation to its RDV or MRV following Equation 2.1.

$$\boldsymbol{NR_{nutrient}} = \frac{\boldsymbol{nutrient}}{\boldsymbol{RDV/MRV}} \cdot \mathbf{100} \quad (2.1)$$

where, $NR_{nutrient}$ is the Nutrient Rich score, nutrient is the daily amount of nutrient ingested (in g), RDV the recommended daily value for qualifying nutrients, and MRV the maximum recommended value for disqualifying nutrients.

As a result, the NR nutrient score is expressed as a percentage of the ingested nutrient in relation to its RDV/MRV. Regarding the nutritional data acquisition, all the required nutritional information on the content of micro and macronutrients for the foodstuffs included in the each case of study has been extracted directly from the Spanish Food Composition Database (AECOSAN, 2021).

2.3.2. Nutrient Rich Diet 9.3

It is well known that consumers are advised to look for nutrient-rich foods rather than discretionary calories. Considering the main recommendations from Van Kernebeek et al., (2014), the nutrient intake associated with one single meal cannot be used to assess the nutritional quality of a daily diet. Therefore, it is considered that the estimation of the nutritional quality of daily menus is the most appropriate for this purpose. The Nutrient Rich Food (NRF9.3) score (Drewnowski, 2009; Fulgoni et al., 2009) is considered the cornerstone of a dietary guidance approach to healthy eating. However, this approach is aimed at evaluating individual products and not daily diets as mentioned. It is for this reason that the Nutrient Rich Diet (NRD9.3) score is considered in this doctoral thesis to estimate the nutritional quality of several dietary patterns. This method was proposed by Van Kernebeek et al. (2014) as a modification of the NRF9.3 index as it is not scaled to energy intake (the former refers to 100 kcal of a given food) and is considered as reference indicator since it has been widely used in nutritional quality and sustainability studies of diets (Batlle-Bayer et al., 2019; Castañé and Antón, 2017; Sara González-García et al., 2018).

The NRD 9.3 index is based on the difference in consumption between a group of nutrients which should be promoted, and other nutrients whose consumption should be limited, taking as reference the Recommended Daily Value (RDV) and the Maximum Recommended Value (MRV) (see equation 2.2.). Accordingly, the nine nutrients (i) to encourage are protein, fiber, calcium, iron, magnesium, potassium, vitamin A, vitamin C, vitamin E; and three nutrients (k) to limit are sodium, saturated fat and added sugar. In this sense, the greater the amount of nutrients ingested to encourage and the smaller the amount of nutrients to limit, the higher the NRD 9.3 index is. Nevertheless, when the 9 nutrients to encourage exceed the Recommended Daily Value (RDV), they are capped to this previous value, to avoid overestimation caused by overconsumption.

$$NRD9.3 = \left(\sum_{i=1}^{i=9} \frac{nutrient_{\ i\ capped}}{RDV_i} - \sum_{k=1}^{k=3} \frac{nutrient_{\ k}}{MRV_k}\right) * 100 \quad (2.2)$$

In the same way as in Section 2.3.1., the required nutritional information on the content of micro and macronutrients for the foodstuffs included in the each case of study has also been extracted directly from the Spanish Food Composition Database (AECOSAN, 2021), and extrapolated to the amount of food consumed.

2.3.3. HEALTH SCORE

The Health Score is another of the nutritional indexes selected to estimate the nutritional quality of dietary patterns in this doctoral thesis. This index was developed by Van Dooren et al. (2014) taking into account the complexity of determining the health benefits of diets (Van Dooren et al., 2014). To this end, ten indicators linked to different food-related diseases, such as obesity, heart diseases and cancer, established by several health organizations such as WHO[1], World Cancer Research Fund (WCRF)[2] or Dutch Health Council (DHC)[3], are considered (See equation 2.3). In general, the interrelationships that support the choice of these indicators according to the mentioned organizations are as follows: i) Reducing the intake of energy-dense foods is convincingly related to a lower risk of obesity; ii) A higher consumption of fruits and vegetables has been proven to lower risk of obesity and cardiovascular diseases; iii) A high intake of dietary fiber is associated with a lower risk of obesity; iv) An increase in the consumption of fish oil is associated with a lower risk of heart disease; v) Lower consumption of saturated fats is related to lower risk of coronary heart diseases; vi) A reduction in alcohol consumption is associated with lower risk of heart diseases and cancer; vii) There is plausible link between the consumption of processed meat, the high consumption of red meat and cancer (Van Dooren et al., 2014).

$$Health\ score = \left(\frac{g\ veg}{200} + \frac{g\ fruit}{200} + \frac{g\ fiber}{30} + \frac{30}{en\ \%\ total\ fat} + \frac{10}{en\ \%\ free\ sugar} + \frac{6}{g\ salt} + \frac{2100}{kcal\ energy}\right) * \frac{100}{7} \quad (2.3)$$

Accordingly, the following parameters have been considered for the estimation: the daily intake of two food groups (i.e., vegetables and fruits), the daily percentage of energy obtained from total fatty acids and free sugars, the daily intake of sodium and fiber and the total daily energy intake (kcal·day^{-1}). Therefore, the amounts of vegetables, fruits and fiber consumed are beneficial elements to encourage. Furthermore, it is not recommended to exceed the reference values for the daily percentage of energy intake obtained from total fatty acids and free sugars and the daily intake of sodium. Additionally, the complete nutritional composition of the foodstuffs for the different case studies has been obtained from the Spanish Food Composition Database (AECOSAN, 2021).

2.3.4. SUSTAINABLE NUTRIENT RICH DIET 3.3

The Sustainable Nutrient Rich Diet 3.3 score considers two of the three dimensions established by FAO and WHO for a sustainable diet (i.e., environment and health) (FAO and WHO, 2019). In this sense, the novel index proposed by Van Dooren et al., (2017)

[1] http://www.who.int/ (accessed January 2021)
[2] https://www.wcrf.org/ (accessed January 2021)
[3] https://www.gezondheidsraad.nl/ (accessed January 2021)

reflects both climate and nutritional impact of diets in a single value. This methodology is a variant of the previously designed Nutrient Rich Food 9.3 (NRF 9.3) index (Drewnowski, 2009), and takes into account the strong correlations that exist between GHG emissions from foodstuffs and their content in certain macronutrients (see Equation 2.4). In this context, there is for instance a strong correlation between animal protein, saturated fats, and sodium and GHG emissions; and a lower correlation between dietary fiber or plant protein and GHG emissions.

Therefore, qualifying macronutrients such as EFA, plant-based protein and dietary fiber are related with plant-based and fish sources, which are low in GHG emissions (Lynch et al., 2018). Otherwise, disqualifying macronutrients such as saturated fatty acids (SFA), sodium and total sugars are related with animal-based products and processed foods, which are higher in GHG emissions (Scarborough et al., 2014).

$$SNRD3.3 = \frac{\left(\frac{g\ EFA}{RDV(g)} - \frac{g\ SFA}{MRV(g)}\right) + \left(\frac{g\ plant\ protein}{RDV(g)} - \frac{g\ sodium}{MRV(g)}\right) + \left(\frac{g\ dietary\ fiber}{RDV(g)} - \frac{g\ sugars}{MRV(g)}\right)}{3 \times \left(\frac{kcal\ energy}{2100\ kcal}\right)} \quad (2.4)$$

As a result, the variant of NRF9.3 is obtained as the Sustainable Nutrient Rich Diet 3.3 (SNRD3.3) since it considers 3 macronutrients to enhance and 3 macronutrients to limit. As detailed in Equation 2.4, the percentages of the daily nutrient values are averaged by dividing the index by 3. Furthermore, the sum of nutrient contributions to their daily reference value is also divided by the contribution of the energy intake (kcal), thus correcting the metabolic energy density so that it remains a dimensionless value. In this way, a high SNRD score (>1) relates to a higher consumption of plant-based products such as vegetables, legumes, fruits, and nuts; an SNRD between -1 and 0 is related with consumption of low-fat milk products, eggs and fish; and an SNRD below -1 is derived from other animal-based products such as red meat, processed meat or high-fat dairy products. Therefore, the nutritional density of the whole dietary habit is considered for the index calculation, rather than relating only the nutrient content of a single food. The reference values for RDV and MRV are taken from Codex Alimentarius (FAO/WHO, 2017) and the European Food Safety Authority (EFSA, 2019).

2.4. Data Envelopment Analysis

The Data Envelopment Analysis (DEA) methodology is used in the **Chapter 7**. The slacks-based DEA model proposed by Tone et al. (2001) is used herein to calculate the multi-criteria efficiency of dietary patterns. DEA is a linear programming methodology that non-parametrically calculates the comparative efficiency of multiple similar entities (DMUs), and projects the inefficient DMUs at the efficient frontier, thereby providing target values for the inefficient entities into efficient ones (Cooper et al., 2007). This is done through the formulation of a model with specific features in terms of metrics (radial or non-radial model), orientation (e.g., input- or output-oriented model), and display of the set of production possibilities (e.g., constant or variable returns to scale). In the case study performed in this doctoral thesis, the specific non-radial DEA model used is the input-oriented slacks-based measure of efficiency model with variable returns to scale (SBM-I-VRS model), formulated herein according to Tone et al. (2001) and Iribarren et al. (2013):

$$\Phi_0 = \text{Min} \left(1 - \frac{1}{\text{M}} \sum_{\text{k}=1}^{\text{M}} \frac{\sigma_{\text{k}0}}{x_{\text{k}0}}\right) \quad (2.5)$$

subject to

$$\sum_{\text{j}=1}^{\text{N}} \lambda_{\text{j}0} x_{\text{kj}} = x_{\text{k}0} - \sigma_{\text{k}0} \quad \forall\ \text{k} \quad (2.6)$$

$$\sum_{\text{j}=1}^{\text{N}} \lambda_{\text{j}0} y_{\text{j}} = y_0 \quad (2.7)$$

$$\lambda_{\text{j}0} \geq 0\ \forall\ \text{j}, \sigma_{\text{k}0} \geq 0\ \forall\ \text{k} \quad (2.8)$$

Where N: number of DMUs; j: index on the DMU; M: number of inputs; k: index on inputs; x_{kj}: amount of input k demanded by DMU j; y_j: amount of output generated by DMU j; 0: index of the DMU under assessment; $(\lambda_{10}, \lambda_{20}, \dots, \lambda_{N0})$: coefficients of linear combination for assessing DMU 0; σ_{k0}: slack (i.e., potential reduction) in the demand of input k by DMU 0; and Φ_0: efficiency score of DMU 0.

The choice of an input-oriented model aims to reduce inputs and ensure at least the same output (i.e., the same nutritional quality). Solving the optimization problem results in the efficiency score (Φ) of each dietary pattern. Efficiency scores lead to discriminate between efficient (Φ = 1) and inefficient (Φ < 1) dietary habits. It should be noted that these efficiency scores act as an index that brings together the different selected criteria to provide a single measure of sustainability of the dietary habits currently present in Spain. In this sense, reporting one single measurement rather than multiple criteria may facilitate the formulation of guidelines and policies based on the best-performing dietary habits identified within the set of entities under assessment.

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SECTION II

THE ATLANTIC DIET

CHAPTER 3

Towards an environmentally sustainable and healthy Atlantic dietary patter: Life cycle carbon footprint and nutritional quality[4]

SUMMARY

Production and consumption of food has a significant effect on climate change. The effect of different consumption habits on the environment should not be underestimated, as there are different studies that mention the environmental impact associated with different foods, especially those of animal origin. The analysis of the Atlantic Diet, as the most common dietary pattern in North-western Spain, serves as an example of a diet with a high consumption of local, fresh, and seasonal products, home cooking and low-processed foods. The evaluation was carried out by quantifying the carbon footprint following the Life Cycle Analysis methodology and identifying its nutritional quality according to the value of the Nutrient Rich Diet 9.3 index. According to the main results, the consumption of livestock products and shellfish is responsible for most GHG emissions (70% of the total). The basic ingredients of the Atlantic diet, such as vegetables and legumes, make a relatively minor contribution (with an impact of 30% of the total) to the total carbon footprint of 3.01 kg $CO_2eq \cdot person^{-1} \cdot day^{-1}$. Regarding the nutritional quality, the Atlantic diet has a high nutritional score (474), mainly due to the low intake of sodium, added sugars and saturated fats (nutrients to be limited in healthy diets). In general, both the carbon footprint and the nutritional index score are consistent with those of other studies on the Mediterranean diet, which has been recognized as beneficial for the environment and health. Therefore, it can be concluded that the Atlantic diet may be recommended from a nutritional and environmental point of view, mainly due to the high intake of seafood and vegetables. The communication of this valuable environmental and nutritional information to consumers should be taken into account when considering strategic actions for the adoption of healthy and sustainable dietary patterns.

[4] Esteve-Llorens[a], X., Darriba[a], C., Moreira, M.T.[a], Feijoo, G.[a], González-García, S.[a], 2019. Towards an environmentally sustainable and healthy Atlantic dietary pattern: Life cycle carbon footprint and nutritional quality. Sci. Total Environ. 646, 704–715. ISSN: 0048-9697. https://doi.org/10.1016/j.scitotenv.2018.07.264.

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CHAPTER 3 - OUTLINE

3.1 INTRODUCTION

Balanced and complete nutrition affects human health and well-being. The effects of nutritional patterns on overweight, cardiovascular disease and other diet-related health problems are widely known (Coelho et al., 2016; Risku-Norja, 2011). The selection of one type of food versus another entails direct consequences in the supply chain, as well as environmental, economic and social impacts associated with the production process (Cencic and Chingwaru, 2010). In particular, food chains that support diets are linked to environmental issues such as greenhouse gas (GHG) emissions, embedded energy consumption and land use (Irz et al., 2016; Castañé and Antón, 2017). Therefore, environmental pressures on food systems are relevant to public health agendas (Sáez-Almendros et al., 2013).

Food production ranges from agricultural and farming activities to manufacturing, refrigeration, retailing, storage, cooking and final disposal of waste (Garnett, 2011; Sáez-Almendros et al., 2013). According to the Intergovernmental Panel on Climate Change , about 30% of total GHG emissions in developed countries are derived from food production (IPCC, 2019), distribution and consumption, and agriculture is responsible for 70-80% of water consumption (Mekonnen and Gerbens-Leenes, 2020). In this regard, researchers are evaluating the sustainability of food production and eating patterns (Donati et al., 2016). According to these studies, lacto-ovo-vegetarian or plant-based diets are more environmentally sustainable than those containing resource-intensive products (e.g., meat-rich diets) (Halpern et al., 2019).

Of special interest is the development of methodologies to analyze the environmental impact of a product or food system with the most objective approach. (Aleksandrowicz et al., 2016; Van de Kamp et al., 2017). Moreover, diets are made up at the same time from a set of foodstuffs, fulfilling the function of satisfying the daily nutritional needs of a human being. The environmental footprints of some diets (e.g., omnivorous, vegetarian, vegan, omega-3 fatty acids enriched) have been quantified according to the Life Cycle Assessment (LCA) methodology (Pimentel and Pimentel, 2003; Coelho et al., 2016). In this sense, numerous studies can be found in the literature in which the relationship between diets, nutritional quality and environmental aspects are evaluated in detail, reporting the health and environmental benefits of adhering to sustainable dietary patterns (Aleksandrowicz et al., 2016; Van de Kamp et al., 2017).

The high consumption of fruits, vegetables and whole grains in the diet is closely related to the reduction of the risk of developing chronic diseases such as cancer and cardiovascular diseases, which are the main causes of death in industrialized countries (Afshin et al., 2017). It is for this reason why healthier, and more fruit and vegetable-rich diets have been identified in southern countries. In contrast, northern countries have diets rich in animal fats and food products of animal origin (González-García et al., 2018).

It is interesting to identify different social contexts and cultural values in relation to food. While food is an individual issue in northern countries, society in central and southern Europe associates food with the social dimension of sharing a meal (Castañé and Antón, 2017).Spain is one of the European countries with the lowest mortality rates for ischemic heart disease (Miller and Lu, 2019). Within the country, regional differences have been identified in this regard. In fact, variations have been reported to be up to 40% lower than the average in northern cities (Medrano et al., 2012). The traditional Atlantic diet is a common dietary pattern in northern Portugal and Galicia (northwest Spain), culturally and climatically similar areas and has been associated with a lower likelihood of myocardial infarction and good metabolic health (Calvo-Malvar et al., 2016; Atlantic Diet Foundation[5]). The Atlantic diet is characterized by an abundant consumption of plant-based products, as well as local and fresh products (seasonal food) with reduced cooking time (Vaz Velho et al., 2016). The consumption of meat (mainly beef and pork) and eggs is reasonable and olive oil is considered as the main source of fat for cooking and seasoning (Calvo-Malvar et al., 2016). Recently, it has been rated as a world reference for a healthy diet (Vaz Velho et al., 2016). The Atlantic diet differs from the Mediterranean - the most popular in southern Spain, in terms of increased consumption of seafood, red meat, pork, milk, potatoes, fruit, vegetables and olive oil (Vaz Velho et al., 2016), which implies significant changes in nutrients and functional components. However, both of them can be taken as examples of healthy diet (Dernini and Berry, 2015; Leis Trabazo et al., 2019).

The Chapter 3 has a twofold objective: to quantify the carbon footprint of the Atlantic diet through a LCA approach associated with the production, distribution and consumption of the different foods that make up this diet, while identifying its nutritional quality. The recommended Atlantic dietary pattern and the corresponding intake data have been considered. The main causes of GHG emissions will be highlighted to identify options for improvement.

3.2. Materials and methods

3.2.1. Weekly menu based on the Atlantic diet

The concept of the Atlantic diet dates to the traditional gastronomy menus from the north-west of the Iberian Peninsula. gastronomy. With the social awareness of a healthy diet, the benefits of this dietary pattern are reflected in a recent study (Vaz Velho et al., 2016) (see Figure 3.1.). It is characterized by i) a high intake of seasonal foods, vegetables, fruits, potatoes, bread and cereals, chestnut, whole nuts, legumes and honey, fish, mollusks, and crustaceans; ii) a moderate consumption of milk, cheese, meat (beef and pork), eggs and iii) cooking methods based on boiling, stewing, grilling, and roasting. An abundant intake of complex sugars, fiber, polyunsaturated fatty acids, vitamins, minerals

[5] https://www.fundaciondietatlantica.com/eng/index.php (accessed January, 2021)

and functional components is therefore guaranteed (Tojo and Leis, 2009; Vaz Velho et al., 2016).

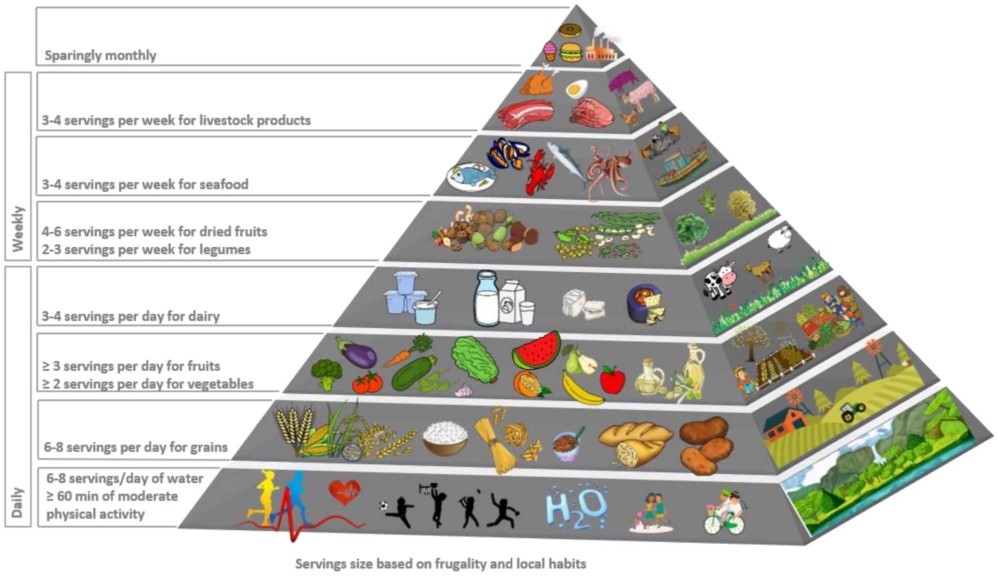

Figure 3.1. Atlantic diet pyramid. The base and the top of the pyramid include the foodstuffs that must be daily consumed or occasionally consumed, respectively.

Although studies can be found in the literature that consider individual meals, daily or annual diets (González-García et al., 2018; Van Kernebeek et al., 2014), a weekly diet has been considered for analysis, as it may facilitate comparison with other types of dietary patterns. Following the recommendation of Tojo and Leis (2009), a weekly diet has been designed– displayed in Table 3.1. – consisting of seven daily menus (daily diets) divided in five meals (breakfast, mid-morning snack, lunch, afternoon snack and dinner) has been designed, as similar as possible to the recommended Galician eating habits (Xunta de Galicia, 2013). This weekly diet is based on 2,100 kcal and corresponds to the energy needs of an active Spanish adult woman (regular physical activity) according to FAO (2014).

Table 3.1. Atlantic diet based weekly menus designed for this study considering the recommended servings of the different food groups. The daily diets have been adjusted to a recommended energy intake of 2,100 kcal.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Breakfast	Glass of milk and bread with tomato	Glass of milk. cereals. nectarine	Glass of milk. Wholemeal bread. orange	Glass of milk. wholemeal cereals. nectarine	Glass of milk. wholemeal bread. orange	Curd with honey. wholemeal bread	Glass of milk. bread. peach
Mid-morning Snack	Orange	Yogurt	Yogurt	Infusion	Apple	Kiwi	Pear
Lunch	Steamed cockles. vegetable cannelloni. nectarine. bread	Vegetables and fruits salad. black rice with cuttlefish. bread	Carrot salad. Galician style conger. two figs. bread	Mackerel with potatoes and roasted peppers. watermelon. bread	Octopus with potatoes. salad. curd with honey. bread	Cod croquettes. vegetable stew. tangerine. bread	Padron peppers. roast beef with potatoes
Afternoon snack	Banana	Melon	Banana	Peach	Banana	Yogurt	Nectarine
Dinner	Grilled beef steak with rice. bread	Grilled pork steak. steamed Brussels sprouts. pear. bread	Pumpkin cream. pear. bread	Pasta salad. fresh cheese. bread	Grilled beef steak with rice and steamed vegetables	Chicken steak with pasta and mushrooms. grapes. bread	Scrambled eggs with mushrooms and pasta
Total energy intake	2,124 kcal	2,101 kcal	2,295 kcal	2,140 kcal	2,051 kcal	2,189 kcal	2,097 kcal

Recommended servings of different food groups have been considered for evaluation (Vaz Velho et al., 2016). Table 3.2. shows the frequency servings for the Atlantic dietary pattern. Although the specific composition of the diet changes with age and sex, this level of uncertainty can be assumed for the estimation of the carbon footprint.

Table 3.2. Main recommendations of servings (s) frequency for each food group for the Atlantic Diet adapted from Velho et al. (2016).

Food group	Servings frequency
Cereals/Grains	6-8 s·day^{-1}
Fruits	3s or more·day^{-1}
Vegetables	2s or more·day^{-1}
Olive oil	3-4s·day^{-1}
Dairy products	3-4s·day^{-1}
Dried fruits	4-6s·week^{-1}
Legumes	2-3s·week^{-1}
Seafood	3-4s·week^{-1}
Meat	3-4s·week^{-1}
Eggs	3-4s·week^{-1}
Sweets	Sparingly monthly

3.2.2. ESTIMATION OF THE ATLANTIC DIET NUTRIENT COMPOSITE SCORE

One of the main objectives of this chapter is to analyze the nutritional quality of the Atlantic diet to identify whether this dietary pattern meets healthy parameters. It is well known that consumers are advised to look for nutrient-rich foods rather than discretionary calories. Considering the main recommendations from Van Kernebeek et al., (2014), the nutrient intake associated with one single meal cannot be used to assess the nutritional quality of a daily diet. Therefore, the nutritional quality has been analyzed through daily menus. This perspective will facilitate comparison with alternative dietary patterns. The Nutrient Rich Food (NRF9.3) score, designed by Fulgoni et al., (2009) is considered the cornerstone of a dietary guidance approach to healthy eating. However, the Nutrient Rich Diet (NRD9.3) score was considered in this study to estimate the nutritional quality of the Atlantic diet. This method has been proposed by Van Kernebeek et al., (2014) as a modification of the NRF9.3 index as it is not scaled to energy intake (the former refers to 100 kcal of a given food). A detailed description of this index, with the corresponding equation (see Equation 2.2), the nutrients involved, and other considerations is provided in Chapter 2 (Section I).

Table 3.3. displays the recommended intake ranges for each nutrient to be promoted and the maximum for each nutrient to be limited, taking into account health recommendations (Castañé and Antón, 2017).

Table 3.3. Recommended nutrients daily intake (RDV) and daily average nutrients composition for the Atlantic Diet (AD).

	Boosting nutrients									Limiting nutrients		
	Protein	Fiber	Vit A	Vit C	Vit E	Ca	Fe	K	Mg	Saturated fat	Added sugar	Na
	g	g	µg	mg	mg	g	mg	g	mg	g	g	g
RDV	50	25	700-3000	60-2000	20-1000	1.0-2.5	18-45	3.5	400	20	50	1.5-2.4

The NRD9.3 score has been estimated for each daily diet previously designed and reported in Table 3.1. In addition, an average score has been calculated with these specific indexes with the aim of obtaining a final dietary quality score for the Atlantic diet. This average score has been benchmarked with others available in the literature (Van Kernebeek et al., 2014) to identify how it is ranked in terms of nutritional quality. Finally, the nutritional quality score has been supplemented with the assessment of individual nutrient scores, considering the 12 nutrients mentioned above. For this purpose, the Nutrient Rich (NR) index for each nutrient is calculated according to the method proposed by Van Kernebeek et al. (2014) (see Equation 2.1). This index reports the nutrient intake in relation to the RDV (see Chapter 2 from Section I).

3.2.3. ESTIMATING THE CARBON FOOTPRINT OF THE ATLANTIC DIET

For the estimation of the carbon footprint of each daily diet that constitutes the weekly menu of the recommended Atlantic diet, the LCA approach, a standardized methodology for the systematic assessment of the environmental burdens of a product or service system at all stages of its life cycle, has been taken into account (ISO 14040, 2006). LCA has increased its application in food analysis in recent years and has been considered as a potential assessment method for environmental profiles of food products and dietary patterns (Goldstein et al., 2016).. Therefore, this study addresses the estimation of GHG emissions in the Atlantic diet considering the recommended dietary patterns with the aim of answering the question "*Is the Atlantic diet a healthy and environmentally sustainable diet?*".

3.2.3.1. FUNCTIONAL UNIT

LCA attempts to quantify the material and energy flows throughout the life cycle of the system under analysis, in this case, daily menus of the Atlantic diet. Thus, a functional unit is required to provide a common basis to report the corresponding carbon footprint and to allow its comparison with those from other dietary patterns. Although different functional units have been considered in related studies the recommended 2,100 kcal per day supply of food, excluding non-dairy beverages, has been considered (FAO, 2014), which is in line with the one selected in other relevant studies available in the literature (Batlle-Bayer et al., 2019; Castañé and Antón, 2017; Scarborough et al., 2014) and allows comparison between the results achieved. In this functional unit, the primary function of the daily diet (i.e., the supply of energy and nutrients for an adult woman) is fulfilled. However, it is important to note that consuming 2,100 kcal per day does not imply a nutritionally adequate diet. For this reason, the assessment of the nutritional score (NRD9.3) is selected to complete this study and give an answer to the objective question.

3.2.3.2. SCOPE OF THE ATLANTIC DIET ANALYSIS

The carbon footprint for each daily diet reported in Table 3.1. will be estimated according to a cradle-to-mouth perspective (see Figure 3.2.). The system analysis has therefore been divided into three stages:

- Food production stage, i.e., production of the different food ingredients that make up each daily menu (breakfast, mid-morning snack, lunch, afternoon snack and dinner). At this stage, a "cradle-to-farm or industry gate" approach was considered, depending on the food product.

- Transport stage, i.e., the distribution of the different food products from the factory or farm gate to the retailer, as well as from the retailer to households.

- Household stage, i.e., preparation of the different menus at households and refrigeration (if necessary).

The carbon footprint of the household stage has been calculated considering three main cooking processes, such as boiling, frying, and baking as well as home storage in refrigerators. The abundance of fresh products in the Atlantic Diet makes large cooking processes unnecessary (Leis Trabazo et al., 2019). For this reason, it has been assumed that only one of the three cooking methods is used for each serving when necessary, in line with Castañé and Antón (2017). According to Sonesson and colleagues, the carbon footprint associated with the cooking process is expected to derive mainly from the energy consumption of household appliances (Sonesson et al., 2003). Regarding home storage, it has been computed the average electricity consumption reported by Muñoz et al. (2010) associated with the use of a combined refrigerator and a freezer. According to that study, electricity requirements correspond with 0.52 kWh per person and day.

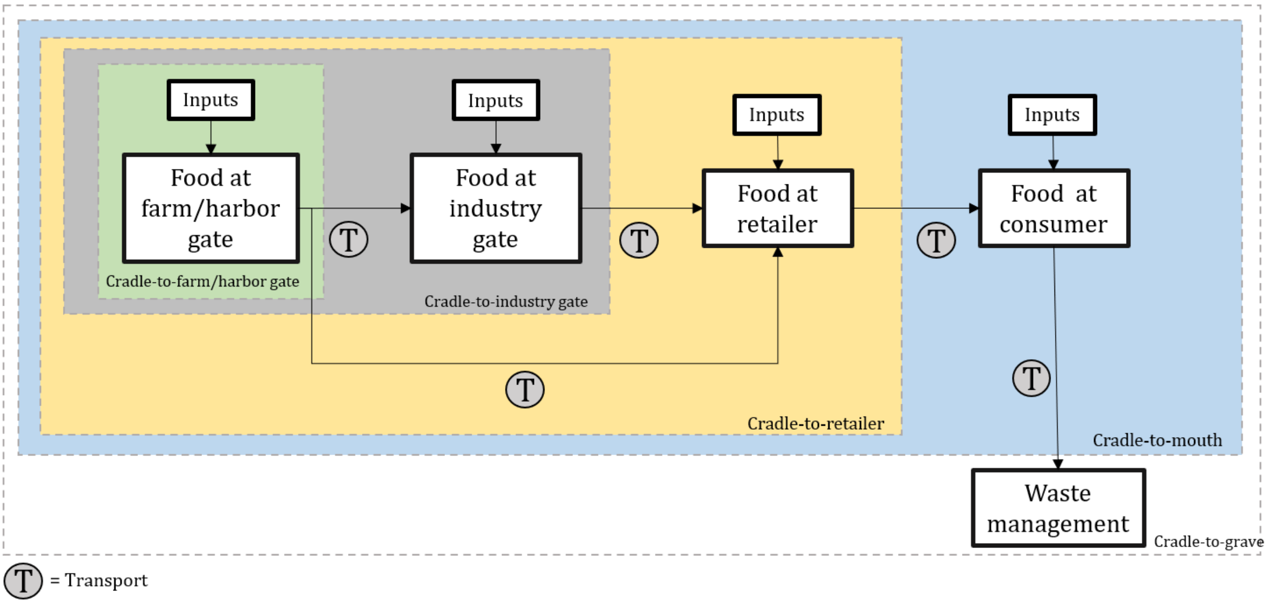

Figure 3.2. System boundaries considered in the analysis of the carbon footprint associated to the recommended Atlantic dietary pattern (cradle-to-mouth) as well as alternative limits available in the literature.

As far as transport activities are concerned, Euro 5 diesel freight lorries (>32 tons) have been considered for transport from the factory/farm gate to retailers for the food produced in Spain. Thus, average distribution distances of 400 km and 60 km (on average) have been estimated for distribution from outside and within Galicia, respectively. For products manufactured outside Spain, an average distance by ship and lorry from their country of origin to Galicia has been considered. In all the situations, refrigerated transport has been considered when necessary. Table 9 of the Appendix displays the origin of each product and the corresponding distances for the transport stage.

Moreover, the transport from retailers to households has also been considered despite their negligible contribution reported in other works (Castañé and Antón, 2017). According to Sonesson et al. (2005), consumers go shopping once a week, mainly on foot

(70%) rather than by car or public transport (30%). In line with González-García et al., (2013), an average distance of about 10 km has been established between the retail trade and households. In our study, we have excluded from the analysis those inputs that can be assumed to change to a lesser extent between diets such as cleaning products, kitchen utensils, cutlery, and dishes, following the recommendations of Pernollet et al., (2017).

3.2.3.3. DATA QUALITY FOR THE ESTIMATION OF CARBON FOOTPRINT OF FOOD PRODUCTS

A sample of 67 food items in the shopping basket have been grouped into 9 different categories, as displayed in Table 1 of the Appendix (fruits, vegetables, legumes, grains, dairy, meat, fish/crustaceans, eggs, olive oil and sweets). The origin of products has been selected based on their most common origin, data availability and, when possible, the consumption of local and seasonal products.

Regarding the data sources considered for the estimation of the GHG emissions associated with each food product, 32 LCA studies focused on the production stage have been considered. The system boundaries in most foods range from cradle-to-farm gate, as displayed in the Table 1 of the Appendix. However, in certain products the system boundaries cover the perspectives of cradle-to-retailer or even cradle-to-grave, as in the case of mushrooms (Leiva et al., 2015) and yoghurt (González-García et al., 2013), respectively. Therefore, in these cases the corresponding GHG emissions have been discarded to be consistent with the system boundaries established in our analysis at the production stage. In other cases, some food products have been assimilated to others because of the lack of information on their production stages and the similarity between production chains. These hypotheses have been considered in the case of nectarine (peach), pumpkin (melon) as well as leek (onion). Food products excluded from the analysis include spices and condiments such as salt. Alcoholic beverages, soft drinks, coffee and infusions have also been excluded from the analysis in line with related studies (Castañé and Antón, 2017; Van Kernebeek et al., 2014). The Ecoinvent ® v3.2 database has been considered for the estimation of GHG emissions linked to background processes (e.g., production of electricity requirements) and for transport activities considering the characterization factors from Intergovernmental Panel on Climate Change (IPCC, 2019).

3.3. RESULTS AND DISCUSSION

3.3.1 NUTRITIONAL QUALITY OF ATLANTIC DAILY DIETS

Table 3.4. shows the nutrient intake for each dietary daily scenario, as well as the average value of the Atlantic dietary pattern. In accordance with the considerations assumed, all diets have been developed to cover all nutritional needs These values are the result of considering the complete menus together with the corresponding amount of each food ingredient and its nutritional composition as can be seen in Tables 2 to 8 of the Appendix.

Table 3.4. Daily average boosting/limiting nutrients intake for the Atlantic diet based weekly menus designed for assessment in this study.

	Boosting nutrients									Limiting nutrients		
	Protein	**Fiber**	**VitA**	**VitC**	**VitE**	**Ca**	**Fe**	**K**	**Mg**	**Saturated fat**	**Added sugar**	**Na**
	g	**g**	**µg**	**mg**	**mg**	**mg**	**mg**	**mg**	**mg**	**g**	**g**	**g**
Monday	120.4	35.5	1692	339	11	1436	73	4578	487	24.2	1.9	1.51
Tuesday	85.5	43.9	635	203	11.9	848	21	5234	483	14.3	2.3	1.50
Wednesday	123.0	36.8	734	250	10	1105	21	4948	407	23.6	1.8	1.33
Thursday	91.0	41.0	1609	463	13	1152	66	4948	505	19.9	2.3	1.50
Friday	88.7	46.6	2108	391	12	1114	19	5071	425	16.5	1.8	1.31
Saturday	88.7	39.2	1680	309	11	1009	17	4479	345	18.1	2.3	1.56
Sunday	111.0	36.3	1680	289	92	921	18	5308	393	18.8	1.9	1.46
Daily average	101.2	39.9	1448	321	23.	1084	33	4938	435	19.3	2.0	1.45

As shown in Table 3.4., the average daily diet reports an intake of numerous nutrients to be encouraged (i.e., protein, fiber, potassium and magnesium) higher than the values recommended in Table 3.3., as well as the average values corresponding to the Atlantic diet reported in the literature (Fundacion Española de la Nutricion, 2004). The high protein intake observed is related to the outstanding consumption of seafood and moderate consumption of meat (mainly beef and pork). All designed daily diets exceed the recommended daily protein intake value of 50 g (up to 2.5 times).

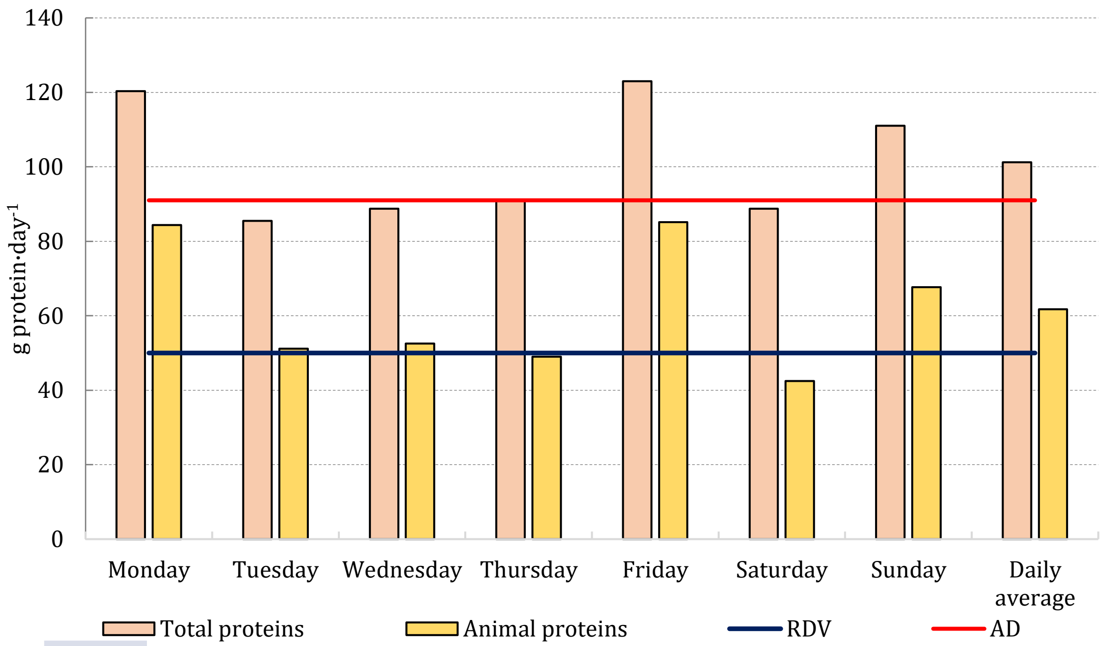

Figure 3.3. Total protein and animal-based protein ingestion per daily diet designed under the Atlantic dietary patterns (g·day-1). RDV – Recommended Daily Value (g·day-1). AD – Established average daily protein intake under Atlantic dietary pattern (g·day-1).

Figure 3.3. represents the daily protein intake for each designed daily diet, together the average dietary value and the recommended daily value suggested by Fundacion

Española de la Nutrición (2004). Protein intake per person ranges from 85.5 to 123 g·day^{-1}, with the percentage of animal protein in relation to total dietary protein varying between 48% and 70%. In line with Van Kernebeek et al. (2014), protein intake is positively associated with AP% (ratio of animal-based protein and total dietary protein). According to the intrinsic characteristics of the Atlantic diet, protein intake comes mainly from seafood and meat, as well as 26% (on average) from dairy products such as milk, yoghurt, and cheese.

Fiber intake can be almost double the recommended value, mainly due to the high intake of fruits, vegetables (e.g., potatoes) and cereals (bread). This high intake of seasonable products also leads to a high dose of potassium. As for magnesium, the remarkable consumption of blue fish (e.g., mackerel) and mollusks (e.g., cockles) along with cereals affects the intake ratio. Regarding other nutrients to encourage, such as vitamins A, C and E, as well as calcium and iron, the amount consumed is within the recommended range. It can be associated with the consumption of a nutrient-enriched product, such as carrots (common as side dish) for vitamin A, pepper (the food product with the highest vitamin C content and a common spice ingredient) and vitamin E, mollusks and dairy products for calcium and fish and mollusks for iron.

For nutrients to limit (saturated fat, added sugar and sodium), their intake is below the recommended limits. The consumption of olive oil and dairy products such as cheese is associated with consumption of saturated fats (both food groups present a serving frequency of 3-4 s·day^{-1}). For added sugar, the intake is around 4% of the maximum recommended value. In designed daily diets, it is associated with the consumption of bread and whole grain cereals. The consumption of bread is a characteristic of the Atlantic diet, being greater than in other types of diets such as the Mediterranean. The outstanding presence of some foodstuffs such as seafood (mackerel, cuttlefish…), bread and meat is mainly responsible for sodium in the diet. Moreover, the Atlantic diet is characterized by a high intake of unsaturated fatty acids, which makes it one of the highest in the world.

Just as a remark, potatoes are a basic food ingredient in the Atlantic diet, unlike other dietary patterns such as Mediterranean or even vegan diets. It is considered an important source of complex carbohydrates, fiber, minerals, vitamins, and water. Another point to take into account is the notable difference between the intake of nutrients (mainly fiber, vitamin C, vitamin E, iron, potassium, magnesium and added sugar) estimated for the daily diets designed and those reported in the literature for the Atlantic diet (Fundacion Española de la Nutricion, 2004). Dietary scenarios depend on individual meals, which are affected by factors such as local conditions, seasonal food, gender and even the economic profile of the family. The relationship between these factors and the nutrients intake could be further explored, but it is beyond the scope of this study.

Regarding the NRD9.3 scores for each diet designed (Table 3.1.), scores range from 418 (corresponding to the diet proposed for Tuesday) to 525 (corresponding to the diet proposed for Thursday), as shown in Figure 3.4. These values are in line with others reported in the literature ranging from 260 to 666, corresponding to other different types of dietary patterns (Nordic, Finish, Indian, English, Mediterranean, vegan...) (González-García et al., 2018).

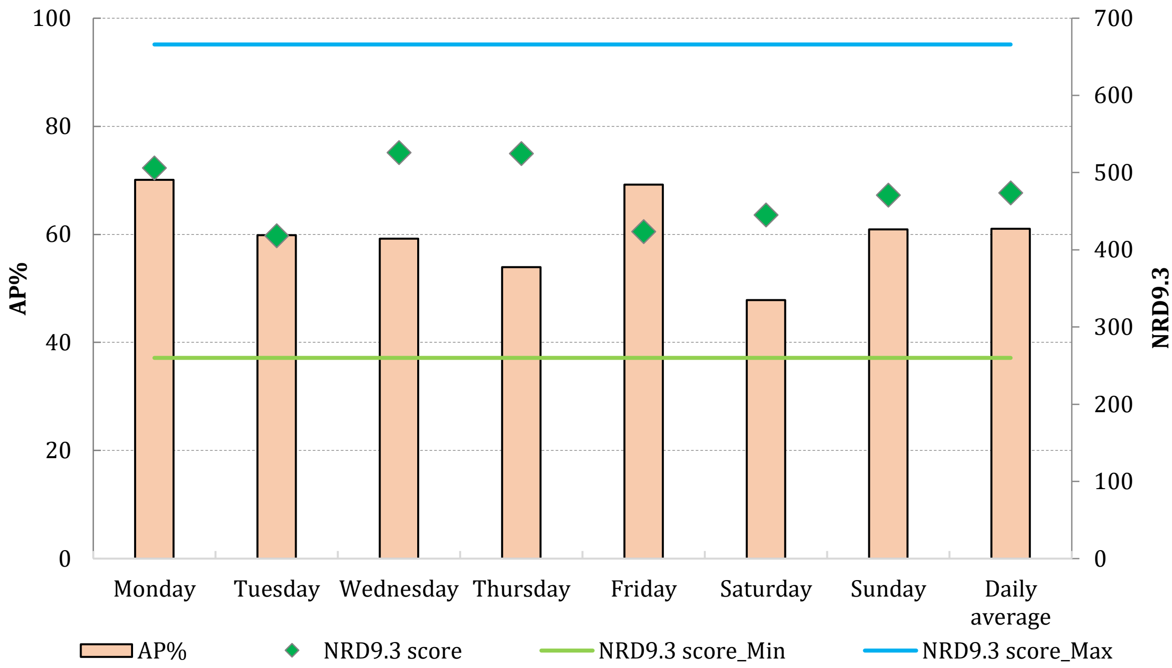

Figure 3.4. NRD9.3 scores and AP% (ratio of animal-based protein and total dietary protein) for each diet that constitutes the designed weekly menu. Minimum (Min) and maximum (Max) NRD9.3 score values found in the literature are also displayed. Numbers on the left (y-axis) represent the AP% (in %). Numbers on the right (y-axis) represent the NRD9.3 scores.

The specific characteristics of each particular type of diet are responsible for the wide range of values in the NRD9.3 index. Moreover, this index is also affected by the above-mentioned parameters (nutrients to encourage/limit as well as RDV) since its estimation is directly dependent on nutrient intake. According to the literature (Van Kernebeek et al., 2014), the relationship between the NRD9.3 score and the percentage of animal protein can vary considerably between studies and there is no a general trend. Risku Norja et al., (2009) and Gerbens-Leenes and Nonhebel (2002) identified a reduction in the NRD9.3 score with an increase in the ratio of animal protein to total protein consumed. In contrast, other authors (Collins and Fairchild, 2007; Saxe et al., 2012) identified the opposite trend. Thus, this effect has been also analyzed in this study considering the different daily diets proposed for analysis along with the average. The results in Figure 3.4. do not show a clear correlation. Some daily diet scenarios have a downward trend, while others have an upward trend in the NRD9.3 score, with an increase in the ratio of animal protein to total daily protein consumed (AP%).

Van Kernebeek et al. (2014) proposed an association between both parameters (NRD9.3 and AP%) considering the results reported in the literature and concluded that the NRD9.3 score is negatively associated with the protein ratio. With this consideration in mind, Figure 3.5. shows the association between the NRD9.3 score and the AP% for the weekly diet proposed here. In addition, the NRD9.3 scores corresponding to these AP% values have also been estimated considering the correlation proposed by Van Kernebeek et al. (2014). The estimated values are 1.1-1.3 times higher than those calculated for our weekly menu. Variations in nutrient composition and dietary characteristics are responsible for these differences. However, in line with Van Kernebeek et al. (2014), the same behavior can be observed, and the score is negatively associated with the AP%. In this sense, these results can be useful and provide information to both consumers and policymakers to achieve healthier food choices in the supermarket or advise on the need to prioritize the intake of plant rather animal protein to reduce the intake of products of animal origin, respectively.

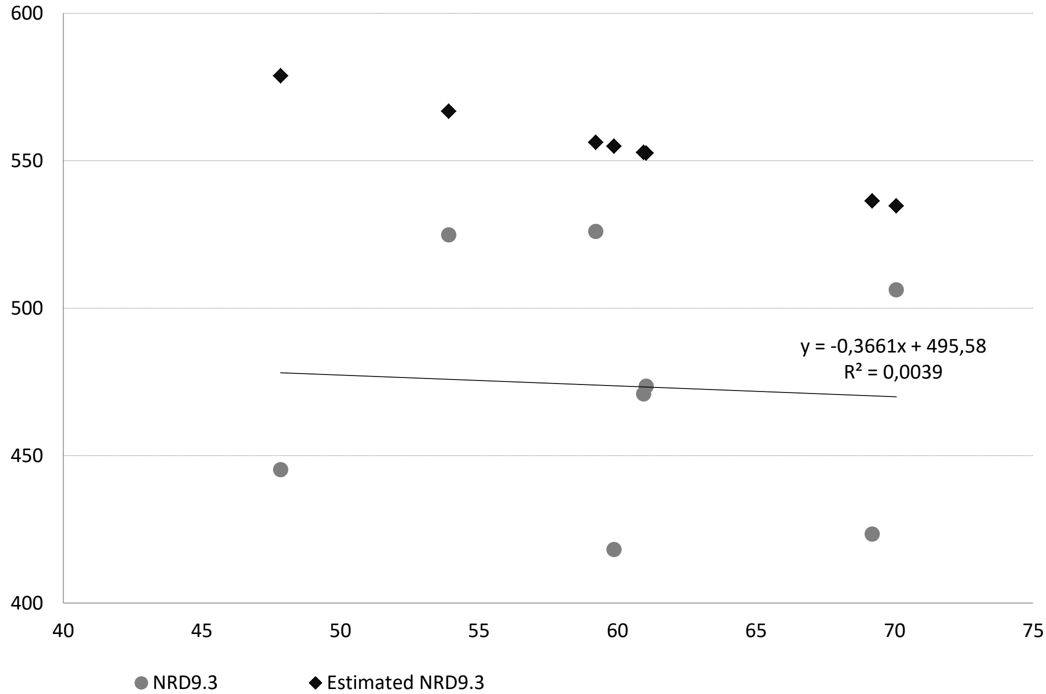

Figure 3.5. Correlation (grey marks) between NRD9.3 scores (y-axis) and AP% (x-axis) for the weekly Atlantic diet designed for analysis. Marks in black have been estimated considering the correlation established by Van Kernebeek et al. (2014) and the AP% values of our daily diets.

Finally, the nutritional quality of the diets has been completed with the estimation of individual nutrient-rich indexes to report dietary intake in relation to recommended daily values. Table 3.5. summarizes the corresponding NR scores per daily diet. NR corresponding to protein, fibre and potassium present a value of 100% since their intake exceeds the recommended values. Magnesium intake also implies outstanding NR indexes, equal or very close to 100%. In accordance with the methodology and to avoid credits for the overconsumption of nutrients to encourage, nutrient intake is assumed to be equal or greater than the RDV. Conversely, values are not rounded to 100% for nutrients to limit if the recommended daily value is exceeded. Nutrients to limit such as sodium and saturated fats generally present high NR indexes (above 56 and 76% respectively). In contrast, the intake of added sugar reports NR indexes below 5% regardless of the designed diet. These values are much lower than those of other diets such as Mediterranean one (Castañé and Antón, 2017), where NR indexes of between 80% and 136% can be expected. These high values are mainly related to the consumption of products such as yoghurt and jam.

According to Table 3.5., the Atlantic diet should report low NR indexes of Vitamin E and C (for Vitamin E below 3% in most proposed daily menus). Improvements in this diet should focus on promoting the intake of ingredients rich on both components, as they are nutrients to encourage. Consumption of citrus products (e.g., orange, mandarin) and nuts (e.g., almonds, hazelnuts) may contribute to increasing the NR-values for Vitamin C and Vitamin E, respectively.

Table 3.5. Nutrient Rich (NR) score for each analyzed nutrient. Scores have been calculated regarding the recommended daily value of each nutrient.

	Boosting nutrients									Limiting nutrients		
	Protein	Fiber	VitA	VitC	VitE	Ca	Fe	K	Mg	Saturated fat	Added sugar	Na
Monday	100	100	91.5	32.9	2.1	82.1	100	100	100	121	3.8	77.5
Tuesday	100	100	34.3	19.7	2.3	48.5	65.9	100	100	71.7	4.6	76.3
Wednesday	100	100	39.7	24.3	1.9	63.1	65.5	100	100	99.4	3.6	68.1
Thursday	100	100	87.0	44.9	2.6	65.8	100	100	100	94.1	4.6	76.8
Friday	100	100	100	38.0	2.3	63.6	61.0	100	100	75.9	2.9	56.3
Saturday	100	100	90.8	30.0	2.2	57.7	53.2	100	86.3	90.5	4.6	80.0
Sunday	100	100	90.8	28.0	18.1	52.7	55.6	100	98.2	94.0	3.8	74.7
Daily average	100	100	76.3	31.1	4.5	61.9	71.6	100	97.8	93.3	4.1	74.3

3.3.2. CARBON FOOTPRINT OF THE ATLANTIC DIET

3.3.2.1. DETAILED ANALYSIS OF CARBON FOOTPRINT FOR THE DESIGNED MENUS

The estimation of GHG emissions (i.e., carbon footprint) corresponding to the menus designed following the recommendations of the Atlantic diet represents an average of 3.01 kg CO_2eq·person^{-1}·day^{-1} (i.e., an absolute value of 21.04 kg CO_2eq per person and week), . This value is slightly higher (~5%) than that reported in the literature focusing on the assessment of the Mediterranean dietary pattern, the most widespread diet in Spain (Batlle-Bayer et al., 2019; Castañé and Antón, 2017) and with characteristics similar to those of the Atlantic. The rationale behind that difference is mostly associated with differences on the dietary patterns as well as with the consideration of refrigeration process at households within the system boundaries, which was excluded from analysis by Castañé and Antón (2017) and which adds to 0.23 kg CO_2eq·person^{-1}·day^{-1}. Considering the same system boundaries, the AD presents a carbon footprint around 8% lower than the corresponding to the Mediterranean one (2.86 kg CO_2eq·person^{-1}·day^{-1}). The shift towards consumption of seafood and fresh products (seasonal food) with limited cooking is behind this difference.

Through a more detailed assessment of the factors responsible for the carbon footprint of the AD, the production of the different food products is identified as a hot spot followed by household (cooking and refrigeration) and transport activities. Contributions from the production stage account for approximately 78% of total GHG emissions, with the remaining 22% is split between the household stage (92%) and transport activities (8%). Figure 3.6. displays the carbon footprint per day, as well as the distribution between the stages included in the analysis (food production, household, and transport).

Figure 3.6. Daily carbon footprint (in kg CO2eq·person-1·day-1) considering the distribution between food production, transport, and household stages.

Regarding the stage of food production (with an average of 2.31 kg CO_2eq·person^{-1}·day^{-1}), it includes all the background activities carried out in the field and on the farm as well as the corresponding industrial processing, if necessary. According to Figure 3.7., meat and dairy production (livestock-based items) is primarily responsible for GHG emissions at this stage (26% and 30%, respectively). Moreover, both food categories are primarily responsible for variations in the carbon footprint between different daily diets. Looking more closely at the contribution of meat production, red meat accounts for 23%, followed by white meat (1.6% pork and 1.4% chicken, respectively).

In contrast, vegetables and fruits are low-carbon food categories (see Table 1 of the Appendix) but consumed in major shares in the Atlantic diet. Therefore, both categories report contributions of 8% of total GHG emissions from the food production stage.

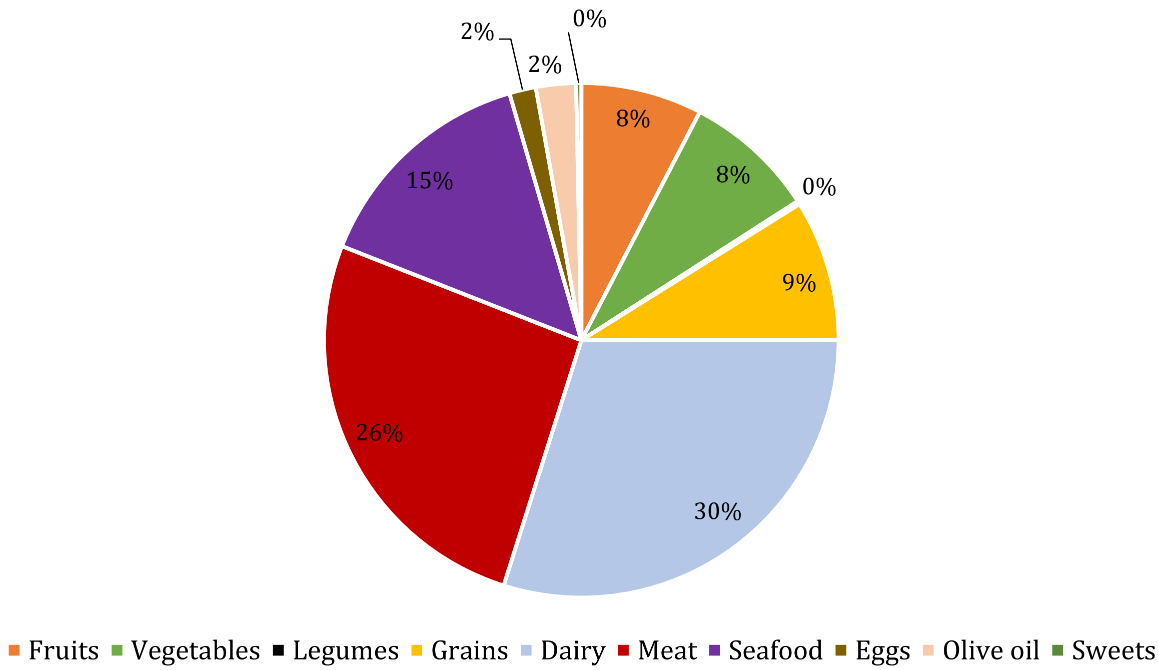

Figure 3.7. Average relative distribution of GHGs emission from food production stage between the food groups involved in the designed 7-day menu.

The remarkable effect on the carbon footprint of livestock products has been highlighted by numerous studies, including those focusing on very different dietary patterns such as Spanish, Peruvian, Western European, American, British and French (Castañé and Antón, 2017; Coelho et al., 2016; Muñoz et al., 2010; Pimentel and Pimentel, 2003; Sáez-Almendros et al., 2013; Scarborough et al., 2014; Vázquez-Rowe et al., 2017). Both products are an important source of protein and energy, and their production involves resource-intensive activities (e.g., fodder production and agricultural activities), as well as methane emissions from ruminant's enteric fermentation.

The seafood category has an outstanding contribution (15% of the total). This contribution is directly related to the remarkable consumption of seafood in the Atlantic diet (Vaz Velho et al., 2016) despite reporting moderate rate of GHG emissions per kg of product (see Table 1 of the Appendix). Grain products such as cereals and bread are basic products of the Atlantic food pyramid, and their contributing ratio rises to 9%.

In terms of GHG emissions from household activities, the total energy required for the 7-day menu is about 33 MJ per week and person split between cooking (60%) and refrigeration (40%). Energy consumption in cooking activities is slightly lower than that of Castañé and Antón (2017), i.e., 30 MJ for the Mediterranean diet. In this sense, the abundance of fresh food products in the Atlantic diet makes complex cooking processes unnecessary, and therefore, implies low energy requirements for cooking. Considering the distribution of the carbon footprint among the contributing stages (see Figure 3.6.), there are no significant differences in the average energy consumption for household activities regardless of the designed daily diet. The consideration of only boiling, frying, and baking as the main cooking processes in the analysis (i.e., as recommended by the Atlantic diet) is also responsible for these negligible differences between the daily menus regarding the household stage. Boiling and frying (the most common daily cooking methods) report similar energy requirements (~0.75 MJ per meal and person, on average). For baking, it is considerably higher, about 4.1 MJ per meal and person.

Finally, the contribution of the transport stage to the global carbon footprint can be considered negligible since it represents less than 2% of the total (on average) with 0.10 kg CO_2eq·person^{-1}·day^{-1}. As far as the origin of food is concerned, Galician products have the lowest GHG emissions due to the shorter distribution distances by lorry. Products of foreign origin are distributed by sea freighter and/or lorry. Maritime transportation does not report outstanding contributions to the carbon footprint despite long distances. Once again, road transport is the main contributing factor to the carbon footprint (five times more than maritime transport).

3.3.2.2. Comparison with results from literature

Numerous studies available in the literature were developed with regard to the environmental assessment of human diets where special attention was paid to the estimation of the carbon footprint (Castañé and Antón, 2017; Coelho et al., 2016; Notarnicola et al., 2017; Pairotti et al., 2015; Pernollet et al., 2017; Röös et al., 2015; Saxe et al., 2012; Scarborough et al., 2014; Vázquez-Rowe et al., 2017). All these studies highlight the limitations of the analysis in the absence of an established methodology and data. The focus on the carbon footprint is based on the availability of data and the awareness of society to avoid anthropogenic GHG emissions to prevent climate change (Springmann et al., 2018). The comparison between our results for the Atlantic diet and those available in the literature for other types of dietary patterns (e.g., Mediterranean, average European, average Spanish, German, Swedish, French, vegan, vegetarian, Nordic, among others) is complex because the results depend on a wide variety of factors and hypotheses.

The number of calories that an average person needs on a daily basis depends on several factors, such as minimum and average dietary energy requirements (Vázquez-Rowe et al., 2017), level of activity, gender, age, weight, geographical location and cultural aspects (EFSA, 2009). Therefore, the range of energy requirements per capita identified in the literature varies from 1,702 kcal·person^{-1}·day^{-1} in Indian diets (Pathak et al., 2010) to 3,596 kcal·person^{-1}·day^{-1} in Western European countries (Tukker et al., 2011). The daily energy intake recommended by the Panel on Dietetic Products, Nutrition and Allergies (EFSA, 2009) is 2,000 kcal·person^{-1}·day^{-1} in European countries. It falls in half the range for a moderately active woman (1,625-2,400 kcal·person^{-1}·day^{-1}), which is consistent with the values recommended in other countries such as the United States, Australia and New Zealand, as well as by the European food industry (EFSA, 2009).

According to experts, this value (2,000 kcal·person^{-1}·day^{-1}) is more consistent with dietary advice for the general population compared to men (2,200-2,300 kcal·person^{-1}·day^{-1}). Therefore, the value set in our study (2,100 kcal·person^{-1}·day^{-1}) could be considered representative for the assessment and coincides with other relevant studies available in the literature (Castañé and Antón, 2017; Collins and Fairchild, 2007; Peters et al., 2007; Sáez-Almendros et al., 2013; Scarborough et al., 2014).

Therefore, to compare the carbon footprints of different dietary scenarios or patterns, the results should be expressed based on the so-called functional unit, in this case, the average energy requirement per person and day. Thus, only the isocaloric diets available in the literature in the range of 2,000-2,100 kcal·person^{-1}·day^{-1} have been considered for comparative analysis of the carbon footprint. This range can be assumed since diets use realistic amounts of food (see Table 3.1.) and it is complex to fix the energy to an identical number.

Consideration of that unit can be used to estimate the change in GHG emissions that would result from changing dietary patterns without modifying the dietary energy intake, which should be more relevant when considering the potential impact of dietary change diets on GHG emissions. According to the CF values depicted in Figure 3.8., the results obtained for the Atlantic diet (Scenarios A and A1-A7) of 3.01 kg CO_2eq·person^{-1}·day^{-1} (on average) are comparable to the values found in other studies focusing on the estimation of this environmental impact for Spanish diets such as Castañé and Antón (2017) (Scenarios B and C) and Sáez-Almendros et al. (2013), who reported about 2.86 and 2.19 kg CO_2eq·person^{-1}·day^{-1}, respectively, for the Mediterranean dietary pattern. Both types of diets are conceived as healthy and are essentially very similar. However, there are two remarkable differences between them, namely: i) the promotion of seafood as the main foodstuff[6] and ii) the high intake of red meat and pork in the Atlantic one. However, attention must be paid to the system boundaries. Sáez-Almendros et al. (2013) considered the same system boundaries as in our study but excluding only refrigeration at households. However, Castañé and Antón (2017) excluded not only home storage but also retailing from the analysis as they considered it irrelevant to global GHGs emissions.

The results of the Atlantic diet are not like those reported by Sáez-Almendros et al. (2013) for the current Spanish diets, based on food balances and consumption surveys (Scenarios E and F, 7.76 and 4.39 kg CO_2 eq·person^{-1}·day^{-1} respectively). These remarkable results are directly related to the source of information considered for the estimation of the carbon footprint. In both cases, diets were based on food consumption/purchase data and not on recommended intake values. Regarding the scenario considering the typical Western dietary pattern (Scenario G), the worst environmental outcomes were reported. Consideration and promotion of the Atlantic diet

[6] http://www.fundaciondiabetes.org/ (accessed January 2021)

would substantially reduce GHG emissions by up to 4.5 times. Excessive consumption of animal products, such as meat and dairy products, is primarily responsible for contributions to GHG emissions due to the high impact of livestock production. The Western dietary pattern is characterized by the outstanding presence of meat and dairy products, up to 8 and 4 times respectively, higher than in other dietary patterns such as the Mediterranean one (Sáez-Almendros et al., 2013). Moreover, the type of food production system (e.g., conventional and organic) can also significantly influence the environmental profile. The same diet with organic or conventional products would present in this sense a different carbon footprint being less for that including foodstuffs produced under an organic regime (Clune et al., 2017).

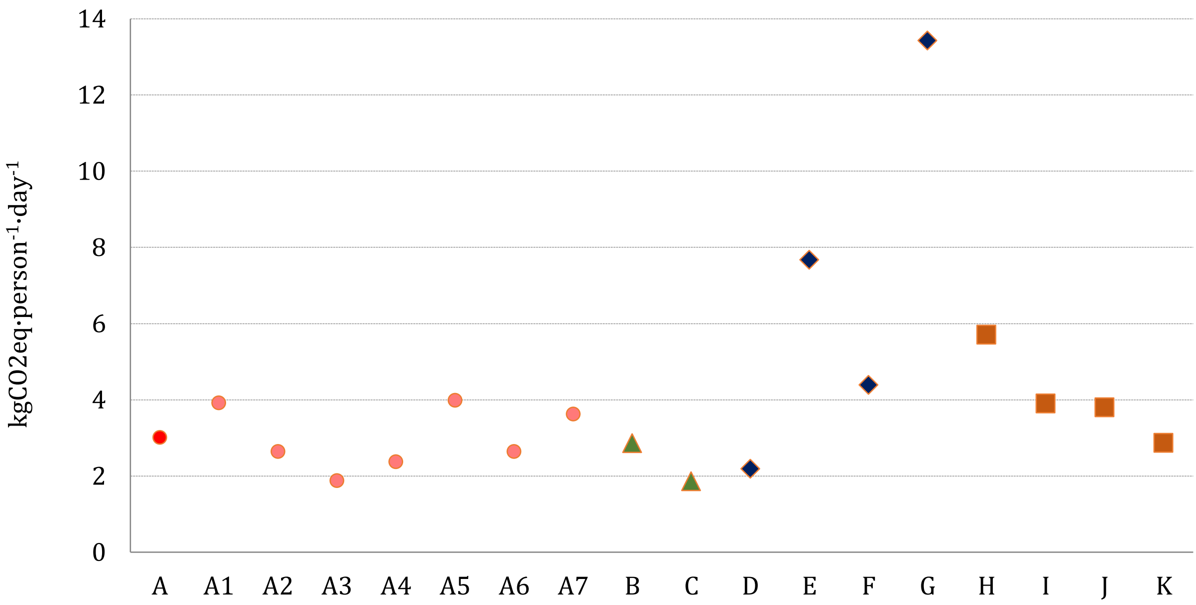

Figure 3.8. Carbon footprint scores for the different diet scenarios considered for comparison. Acronyms: A – average Atlantic diet; A1-A7 – designed daily Atlantic diets; B and C from Castañé and Antón (2017); D, E, F and G from Sáez-Almendros et al. (2013); H, I, J and K from Scarborough et al. (2014).

For the values proposed by Scarborough et al. (2014), the meat-rich diet reported the worst carbon footprint score. Seafood-rich and vegetarian diets reported similar scores (3.90 and 3.80 $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$). The vegan diet score is closing like those for the Atlantic and Mediterranean diets. Therefore, according to scientific literature, the presence of food products of animal origin in the dietary pattern contributes significantly to increasing GHG emissions, which demonstrates the positive relationship between dietary CF and the ratio of animal-based products.

Moreover, attention must be paid to the quality of data sources and system boundaries definition. In our estimation, household stage includes not only cooking but also refrigeration. Several studies available in the literature remark the outstanding contribution from energy use in household storage to the global carbon footprint of a dietary choice (Berlin and Sund, 2010; Heller et al., 2013; Muñoz et al., 2010; Sáez-

Almendros et al., 2013). However, other authors (Castañé and Antón, 2017), excluded this cold storage from analysis. According to our results, refrigeration at household is close to 10% (in average), being an important hot spot in the carbon footprint. The exclusion of this factor from the system boundaries should derive into an average carbon footprint of 2.78 $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$ for the Atlantic diet being this value under the one estimated for the Mediterranean diet by Castañé and Antón (2017). Regarding data quality, the way in which foodstuffs are produced, cultivated, or farmed potentially affects GHG emission (González-García et al., 2018). Thus, the definition of both system boundaries and food production strategies are issue which require special attention mostly if the carbon footprint profiles are going to be compared between dietary choices as well as in decision making strategies

As final recommendations to moving dietary patterns towards more environmentally sustainable ones, the following actions should be taken into consideration:

- To promote the reduction of meat and dairy products by increasing consumption of plant-based products
- To promote the consumption of local and seasonal products, which should lead to a reduction in transport activities and management, respectively
- Reduction of red meat intake by consuming white meat such as chicken and pork
- Social campaign (cultural training, special taxes for ecologic products, …) to promote the benefits of environmentally sustainable diets.

3.4. CONCLUSIONS

According to the main findings reported in this study, the Atlantic diet can be considered beneficial not only from a health, but also from an environmental perspective due to the significant consumption of plant-based products compared to other dietary patterns richer on livestock products. Moreover, the characteristics of the Atlantic diet, based on promoting the consumption of seasonal, fresh, and local products, home-made cooking and low-processed foods also contribute to its low carbon footprint. In this sense, it can be considered as a sustainable diet as defined by FAO, since it has a low environmental impact and contributes to food safety and quality (FAO and WHO, 2019).

In terms of contributions to the carbon footprint, the food production stage is primarily responsible for GHG emissions, followed by the cooking stage and transport activities. Meat, dairy, and seafood products have the highest individual footprint, especially cheese and beef, although their quantities consumed are not as important as other foods such as vegetables or fruits, which are considered basic foods in the recommended Atlantic diet. Regarding the nutritional quality, daily diets with higher NRD9.3 scores should be promoted since they are linked to lower intake of total protein and animal-based products. According to our results, daily diets with higher values of AP are associated with higher GHGs emissions. In this way, the possibility of a change in the direction of a lower consumption of animal protein is related with more sustainable diets, as mentioned in several studies in many countries (Perignon et al., 2016).

The total carbon footprint of the diet could be reduced by minimizing the intake of livestock products in agreement with other studies. Thus, even though the ingested quantities of meat and dairy products are not very high in the Atlantic pattern, they could still be reduced, being compensated for by the intake of plant origin protein. The increase in the nutritional quality together with the improvement of the carbon footprint associated to the shift of protein intake from animal to vegetable origin needs to be analyzed in more detail. Although this study focuses on outlining a designed Atlantic diet, following recommendations, future research should consider the current consumption trends of the region, with the same purpose of linking the environmental and nutritional quality, but under real consumption conditions, which could be compared with the results from this study. In addition, it would be interesting to include socioeconomic variables, relating them to those mentioned above. Further research should pay attention to how to communicate environmental and nutritional dietary information that is attractive and valuable to consumers. The design of labels or logos could be considered as a strategic solution to promote sustainable food consumption, but comprehensive educational programs must be developed.

3.5. REFERENCES

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APPENDIX

Table 1. Carbon footprint values and references considered for the different foodstuffs that constitute the shopping basket of the designed menus following the recommended Atlantic dietary pattern.

	Food product	kg CO_2eq·kg^{-1}	Location	Reference	Study boundaries
Fruits	Green plums	0.12	Spain	Aguilera et al (2015 b)	Cradle to farm gate
	Prunes	1.80	United Kingdom	Berners-Lee et al (2012)	Cradle to retail
	Strawberries	0.33	Spain	Gunady et al (2012)	Cradle to retail
	Pumpkin	0.30	Spain	Aguilera et al (2015 b)	Cradle to farm gate
	Kiwi	0.33	New Zealand	Mithraratne et al (2010)	Cradle to grave
	Orange	0.15	Spain	Aguilera et al (2015 b)	Cradle to farm gate
	Mandarins	0.15			
	Apple	0.12			
	Peach	0.12			
	Melon	0.24			
	Nectarine	0.12			
	Pineapple	0.95	Ghana	West Africa Fair Fruit (2011)	Cradle to retail
	Banana	0.30	Spain	Aguilera et al (2015 b)	Cradle to farm gate
	Watermelon	0.30			
	White grapes	0.12			
	Orange juice	0.67	Spain	Doublet et al (2013)	Cradle to industry gate
	Figs	0.12	Spain	Aguilera et al (2015 b)	Cradle to farm gate
	Raisins	1.80	United Kingdom	Berners-Lee et al (2012)	Cradle to retail
Vegetables	Garlic	0.39	Iran	Khoshnevisan and Rafiee (2013)	Cradle to farm gate
	Celery	0.24	Spain	Aguilera et al (2015 a)	Cradle to farm gate
	Mushrooms	4.42	Spain	Leiva et al (2015)	Cradle to farm gate
	Cucumber	0.18	Switzerland	Marton and Kägi (2010)	Cradle to farm gate
	Onion	0.24	Spain	Aguilera et al (2015 a)	Cradle to farm gate
	Carrot	0.23	Sweden	Gottfridsson (2013)	Cradle to farm retail
	Boletus	4.42	Spain	Leiva et al (2015)	Cradle to farm retail

Table 1. (Continued)

	Food product	kg CO2eq·kg-1	Location	Reference	Study boundaries
	Cabbage	0.24	Spain	Aguilera et al (2015 a)	Cradle to farm gate
	Brussels sprouts	0.24			
	Cauliflower	0.24			
	Asparagus	0.24			
	Tomato	0.22	Spain	Martínez-Blanco et al (2011)	Cradle to farm gate
	Lettuce	0.24	Spain	Aguilera et al (2015 a)	Cradle to farm gate
	Potatoes	0.24			
	Green pepper	0.22			
	Red pepper	0.22			
	Padrón pepper	0.22			
	Leek	0.24			
	Radish	0.24			
	Beetroot	0.24			
Legumes	Beans	0.23			
	Peas	0.23			
	Rice	1.66			
	Coffee	0.50	Brazil	Humbert et al (2009)	Cradle to grave
Grains	Wholemeal cereals	4.00	Sweden	Carlsson-Kanyama et al (2003)	Cradle to retail
	Wholemeal biscuits	4.00			
	Pasta	0.45	Spain	Aguilera et al (2015a) / Röös et al (2011)	Cradle to retail
	Bread	0.67	Spain	Aguilera et al (2015a) / Andersson and Ohlsson (1999)	Cradle to grave
Dairy	Curd	1.77	Spain	González-García et al (2013b)	Cradle to grave
	Yogurt	1.77			
	Milk	1.23	Spain	Ballús (2014)	Cradle to farm gate
	Fresh cheese	7.42	Italy	Palmieri et al (2017)	Cradle to industry gate
	Cow cheese	10.44	Spain	González-García et al (2013a)	Cradle to industry gate
Meat	Chicken	3.00	Portugal	González-García (2014)	Cradle to industry gate
	Pork	3.42	Spain	Noya et al (2017)	Cradle to farm gate
	Beef	9.33	Spain	Solid Forest (2011b)	Cradle to industry gate

Table 1. (Continued)

	Food product	kg $CO_2eq \cdot kg^{-1}$	Location	Reference	Study boundaries
Seafood	Tuna	1.56	Spain	Hospido and Tyedmers (2005)	Cradle to harbor gate
	Cod	2.43	Sweden	Ziegler et al (2003)	Cradle to harbor gate
	Cockles	1.59	Spain	Iribarren et al (2010)	Cradle to harbour gate
	Calamari	3.86	Spain¥	Iribarren et al (2011)	Cradle to harbor gate
	Octopus	4.11			
	Cuttlefish	6.39			
	Mackerel	0.80	Spain	Vázquez-Rowe et al (2010)	Cradle to harbor gate
	Sardines	0.36	Portugal	Almeida et al (2014)	Cradle to harbor gate
Eggs		1.80	Spain	Nielsen et al (2013)	Cradle to farm gate
Olive oil		2.10	Spain	Guzmán and Alonso (2008)	Cradle to farm gate
Sweets	Honey	1.00	United Kingdom	Scarborough et al (2013)	Cradle to farm gate
	White sugar	0.61	Spain	Klenk et al. (2012)	Cradle to industry gate

¥Port located in Galicia (NW Spain). Fishing zone in Mauritania

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Table 2. Nutritional composition of the Monday Atlantic diet menu.

MONDAY													
Food	amount (g)	Protein (g)	Fiber (g)	Vit A (µg)	Vit C (mg)	Vit E (mg)	Ca (mg)	Fe (mg)	K (mg)	Mg (mg)	Sat. fat (g)	Ad. sugar (g)	Na (mg)
Milk	250	8.0	0.0	51.3	7.5	0.2	285.0	0.1	415.0	25.0	2.4	0.0	115.0
Bread	40	4.4	2.4	0.0	0.1	0.3	39.6	1.5	88.8	23.2	0.3	0.5	212.0
Tomato	25	0.2	0.3	20.5	4.8	0.2	2.8	0.1	59.0	2.5	0.0	0.0	4.5
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Orange	325	2.6	6.5	149.5	162.5	0.7	117.0	1.0	650.0	39.0	0.1	0.0	9.8
Cockle	250	26.8	0.0	625.0	0.0	1.0	320.0	60.0	785.0	127.5	0.1	0.0	140.0
Cauliflower	60	1.2	1.4	0.0	28.2	0.0	13.2	0.3	115.8	7.2	0.0	0.0	14.4
Milk	50	1.6	0.0	10.3	1.5	0.0	57.0	0.0	83.0	5.0	0.5	0.0	23.0
Cheese	50	11.1	0.0	170.0	0.0	0.3	381.9	0.1	46.2	13.7	9.0	0.0	210.1
Carrot	40	0.3	1.0	538.4	2.8	0.2	16.8	0.1	114.4	4.0	0.0	0.0	28.0
Leek	40	0.6	1.1	33.2	7.2	0.3	12.4	0.4	102.4	4.4	0.0	0.0	4.8
Pasta	20	2.5	1.0	0.0	0.0	0.0	4.8	0.4	47.2	11.0	0.0	0.0	1.0
Cabbage	15	0.5	0.5	24.9	9.3	0.0	8.0	0.2	48.0	1.1	0.0	0.0	0.8
Wheat flour	10	1.0	0.4	0.0	0.0	0.0	1.6	0.1	13.5	2.0	0.0	0.0	0.3
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Bread	60	6.5	3.6	0.0	0.2	0.4	59.4	2.3	133.2	34.8	0.4	0.7	318.0
Nectarine	250	3.5	5.5	27.5	92.5	2.3	17.5	1.0	425.0	25.0	0.0	0.0	2.5
Banana	225	2.7	7.7	40.5	22.5	0.5	20.3	1.4	787.5	85.5	0.2	0.0	2.3
Beef	125	36.9	0.0	0.0	0.0	0.2	15.0	1.5	472.5	28.8	5.5	0.0	105.0
Rice	45	3.4	0.6	0.0	0.2	0.0	4.6	0.4	58.5	12.6	0.1	0.0	2.0
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Bread	60	6.5	3.6	0.0	0.2	0.4	59.4	2.3	133.2	34.8	0.4	0.7	318.0
Total	1970	120.4	35.5	1691.9	339.4	10.6	1436.2	73.0	4578.2	487.0	24.2	1.9	1511.3

Table 3. Nutritional composition of the Tuesday Atlantic diet menu.

TUESDAY													
Food	amount (g)	Protein (g)	Fiber (g)	Vit A (μg)	Vit C (mg)	Vit E (mg)	Ca (mg)	Fe (mg)	K (mg)	Mg (mg)	Sat. fat (g)	Ad. sugar (g)	Na (mg)
Milk	250	8.0	0.0	51.3	7.5	0.2	285.0	0.1	415.0	25.0	2.4	0.0	115.0
Peach	250	1.5	3.5	42.5	20.0	1.3	20.0	1.0	650.0	22.5	0.5	0.0	7.5
Cereals	30	4.2	8.7	0.0	15.9	0.7	21.0	4.5	345.0	102.0	0.1	0.9	240.0
Yogurt	125	5.4	0.0	1.0	2.0	0.0	175.0	0.1	233.8	17.1	0.1	0.0	71.3
Sugar	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Lettuce	100	1.1	1.5	8.0	12.2	0.5	34.7	1.0	220.0	8.7	0.1	0.0	3.0
Apple	70	0.2	1.4	2.8	2.1	0.4	4.2	0.3	69.3	3.5	0.1	0.0	1.4
Tomato	60	0.5	0.7	49.2	11.4	0.5	6.6	0.3	141.6	6.0	0.0	0.0	10.8
Carrot	30	0.2	0.8	403.8	2.1	0.2	12.6	0.1	85.8	3.0	0.0	0.0	21.0
Asparagus	20	0.6	0.3	10.6	4.3	0.4	5.5	0.3	41.4	2.5	0.0	0.0	0.6
Raisins	20	0.5	1.3	1.0	0.2	0.0	16.0	0.5	156.4	8.2	0.0	0.0	4.2
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Rice	70	5.3	1.0	0.0	0.2	0.1	7.1	0.6	91.0	19.5	0.1	0.0	3.1
Cuttlefish	60	10.6	0.0	1.2	0.0	1.4	22.8	1.4	256.2	19.2	0.1	0.0	226.8
Calamari	50	7.0	0.0	7.5	0.0	0.6	10.2	2.0	158.2	15.8	0.2	0.0	68.3
Onion	40	0.5	0.7	0.0	2.8	0.2	10.2	0.1	64.8	1.7	0.0	0.0	1.2
White wine	45	0.0	0.0	0.0	0.0	0.0	4.1	0.3	36.9	4.5	0.0	0.0	0.9
Banana	225	2.7	7.7	40.5	22.5	0.5	20.3	1.4	787.5	85.5	0.2	0.0	2.3
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Bread	60	6.5	3.6	0.0	0.2	0.4	59.4	2.3	133.2	34.8	0.4	0.7	318.0
Melon	150	0.9	1.5	6.0	37.5	0.2	21.0	0.6	480.0	25.5	0.0	0.0	21.0
Beef	75	20.3	0.0	0.0	0.0	0.1	9.0	0.8	217.5	15.0	4.1	0.0	45.0
Brussels sprouts	50	2.0	2.2	6.5	55.0	0.5	15.5	0.6	205.5	11.5	0.1	0.0	4.5
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Bread	60	6.5	3.6	0.0	0.2	0.4	59.4	2.3	133.2	34.8	0.4	0.7	318.0
Pear	240	1.0	5.5	2.4	7.2	0.0	28.8	0.5	312.0	16.8	0.0	0.0	4.8
Total	2114	85.5	43.9	635.2	203.3	11.9	848.3	20.8	5234.3	483.2	14.3	2.3	1488.5

Table 4. Nutritional composition of the Wednesday Atlantic diet menu.

WEDNESDAY													
Food	amount (g)	Protein (g)	Fiber (g)	Vit A (µg)	Vit C (mg)	Vit E (mg)	Ca (mg)	Fe (mg)	K (mg)	Mg (mg)	Sat. fat (g)	Ad. sugar (g)	Na (mg)
Milk	250	8.0	0.0	51.3	7.5	0.2	285.0	0.1	415.0	25.0	2.4	0.0	115.0
Bread	30	3.3	1.8	0.0	0.1	0.2	29.7	1.1	66.6	17.4	0.2	0.4	159.0
Orange	325	2.6	6.5	149.5	162.5	0.7	117.0	1.0	650.0	39.0	0.1	0.0	9.8
Wholemeal biscuits	16	1.6	2.0	12.2	0.0	0.2	53.3	0.4	32.0	4.5	0.7	0.0	48.0
Carrot	40	0.3	1.0	538.4	2.8	0.2	16.8	0.1	114.4	4.0	0.0	0.0	28.0
Green pepper	40	0.5	0.7	36.0	60.8	0.3	3.6	0.2	62.0	3.2	0.1	0.0	2.4
Red pepper	40	0.5	0.7	36.0	60.8	0.3	3.6	0.2	62.0	3.2	0.1	0.0	2.4
Beetroot	25	0.3	0.6	0.0	0.7	0.0	4.8	0.1	47.5	3.3	0.0	0.0	30.0
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Vinegar	7	0.0	0.0	0.0	0.0	0.0	0.4	0.0	2.7	0.3	0.0	0.0	0.6
Sardines	250	41.7	0.0	141.5	0.0	3.6	208.3	6.3	46.3	59.6	6.5	0.0	143.8
Potato	170	4.0	3.1	0.0	20.7	0.1	11.6	1.2	702.5	27.1	0.1	0.0	12.3
Onion	67.5	0.8	1.2	0.0	4.7	0.3	17.1	0.2	109.4	2.8	0.0	0.0	2.0
Tomato	37.5	0.3	0.4	30.8	7.1	0.3	4.1	0.2	88.5	3.8	0.0	0.0	6.8
White wine	11.45	0.0	0.0	0.0	0.0	0.0	1.0	0.1	9.4	1.1	0.0	0.0	0.2
Olive oil	3.5	0.0	0.0	0.1	0.0	0.4	0.0	0.0	0.0	0.0	0.6	0.0	0.0
Bread	60	6.5	3.6	0.0	0.2	0.4	59.4	2.3	133.2	34.8	0.4	0.7	318.0
Figs	80	1.0	2.0	6.4	1.6	0.7	30.4	0.5	216.0	16.0	0.1	0.0	1.6
Banana	225	2.7	7.7	40.5	22.5	0.5	20.3	1.4	787.5	85.5	0.2	0.0	2.3
Pumpkin	100	1.2	2.4	34.0	12.0	0.1	18.0	0.4	304.0	10.0	0.3	0.0	1.0
Potato	100	2.4	1.8	0.0	12.2	0.1	6.8	0.7	413.3	15.9	0.1	0.0	7.3
Milk	90	2.9	0.0	18.5	2.7	0.1	102.6	0.0	149.4	9.0	0.9	0.0	41.4
Carrot	75	0.6	2.0	1009.5	5.3	0.4	31.5	0.2	214.5	7.5	0.0	0.0	52.5
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Pear	240	1.0	5.5	2.4	7.2	0.0	28.8	0.5	312.0	16.8	0.0	0.0	4.8
Bread	60	6.5	3.6	0.0	0.2	0.4	59.4	2.3	133.2	34.8	0.4	0.7	318.0
Total	2363	88.7	46.6	2107.6	391.4	11.8	1113.5	19.2	5071.2	424.5	16.4	1.8	1306.9

Table 5. Nutritional composition of the Thursday Atlantic diet menu.

THURSDAY													
Food	Amount (g)	Protein (g)	Fiber (g)	Vit A (µg)	Vit C (mg)	Vit E (mg)	Ca (mg)	Fe (mg)	K (mg)	Mg (mg)	Sat. fat (g)	Ad. sugar (g)	Na (mg)
Milk	250	8.0	0.0	51.3	7.5	0.2	285.0	0.1	415.0	25.0	2.4	0.0	115.0
Wholemeal cereals	30	4.2	8.7	0.0	15.9	0.7	21.0	4.5	345.0	102.0	0.1	0.9	240.0
Nectarine	250	3.5	5.5	27.5	92.5	2.3	17.5	1.0	425.0	25.0	0.0	0.0	2.5
Wholemeal biscuits	16	1.6	2.0	12.2	0.0	0.2	53.3	0.4	32.0	4.5	0.7	0.0	48.0
Horse mackerel	200	21.4	0.0	500.0	0.0	0.8	256.0	48.0	628.0	102.0	0.1	0.0	112.0
Flour	10	1.0	0.4	0.0	0.0	0.0	1.6	0.1	13.5	2.0	0.0	0.0	0.3
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Vinegar	7	0.0	0.0	0.0	0.0	0.0	0.4	0.0	2.7	0.3	0.0	0.0	0.6
Potato	200	4.8	3.6	0.0	24.3	0.1	13.7	1.4	826.5	31.8	0.1	0.0	14.5
Red pepper	90	1.2	1.6	81.0	136.8	0.8	8.1	0.4	139.5	7.2	0.1	0.0	5.4
Green pepper	90	1.2	1.6	81.0	136.8	0.8	8.1	0.4	139.5	7.2	0.1	0.0	5.4
Onion	40	0.5	0.7	0.0	2.8	0.2	10.2	0.1	64.8	1.7	0.0	0.0	1.2
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Bread	60	6.5	3.6	0.0	0.2	0.4	59.4	2.3	133.2	34.8	0.4	0.7	318.0
Watermelon	350	1.4	1.8	63.0	17.5	0.4	24.5	1.1	420.0	38.5	0.4	0.0	14.0
Peach	250	1.5	3.5	42.5	20.0	1.3	20.0	1.0	650.0	22.5	0.5	0.0	7.5
Pasta	60	7.5	3.0	0.0	0.0	0.0	14.4	1.1	141.6	33.0	0.1	0.0	3.0
Carrot	40	0.3	1.0	538.4	2.8	0.2	16.8	0.1	114.4	4.0	0.0	0.0	28.0
Egg	30	3.8	0.0	57.0	0.0	0.3	17.1	0.6	39.0	3.6	0.9	0.0	42.0
Tuna	30	6.6	0.0	7.8	0.0	0.3	4.8	0.4	120.0	9.9	0.3	0.0	14.1
Radish	20	0.1	0.2	0.4	4.6	0.0	4.0	0.2	48.6	1.4	0.0	0.0	2.4
Cucumber	15	0.1	0.1	0.3	0.8	0.0	2.9	0.0	22.5	1.8	1.1	0.0	0.5
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Vinegar	7	0.0	0.0	0.0	0.0	0.0	0.4	0.0	2.7	0.3	0.0	0.0	0.6
Fresh cheese	75	9.3	0.0	145.5	0.0	0.4	253.5	0.4	90.8	12.0	7.1	0.0	204.0
Bread	60	6.5	3.6	0.0	0.2	0.4	59.4	2.3	133.2	34.8	0.4	0.7	318.0
Total	2210	91.0	41.0	1608.8	462.6	13.3	1152.0	65.7	4947.5	505.3	19.9	2.3	1496.9

Table 6. Nutritional composition of the Friday Atlantic diet menu.

FRIDAY													
Food	Amount (g)	Protein (g)	Fiber (g)	Vit A (µg)	Vit C (mg)	Vit E (mg)	Ca (mg)	Fe (mg)	K (mg)	Mg (mg)	Sat. fat (g)	Ad. sugar (g)	Na (mg)
Milk	250	8.0	0.0	51.3	7.5	0.2	285.0	0.1	415.0	25.0	2.4	0.0	115.0
Bread	30	3.3	1.8	0.0	0.1	0.2	29.7	1.1	66.6	17.4	0.2	0.4	159.0
Orange	325	2.6	6.5	149.5	162.5	0.7	117.0	1.0	650.0	39.0	0.1	0.0	9.8
Apple	250	0.8	5.0	10.0	7.5	1.3	15.0	1.0	247.5	12.5	0.5	0.0	5.0
Octopus	250	33.5	0.0	140.0	0.0	0.0	76.0	3.8	538.1	76.3	0.0	0.0	63.3
Potato	180	4.3	3.2	0.0	21.9	0.1	12.3	1.2	743.9	28.7	0.1	0.0	13.1
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Lettuce	80	0.9	1.2	6.4	9.8	0.4	27.8	0.8	176.0	7.0	0.1	0.0	2.4
Cucumber	50	0.4	0.4	1.0	2.5	0.0	9.5	0.2	75.0	6.0	3.7	0.0	1.5
Tomato	50	0.5	0.6	41.0	9.5	0.4	5.5	0.3	118.0	5.0	0.0	0.0	9.0
Onion	20	0.5	0.7	0.0	2.8	0.2	10.2	0.1	64.8	1.7	0.0	0.0	1.2
Olives	20	0.3	1.0	9.6	0.0	0.3	12.8	0.4	86.4	4.4	0.5	0.0	10.8
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Vinegar	7	0.0	0.0	0.0	0.0	0.0	0.4	0.0	2.7	0.3	0.0	0.0	0.6
Bread	60	6.5	3.6	0.0	0.2	0.4	59.4	2.3	133.2	34.8	0.4	0.7	318.0
Curd	150	6.8	0.0	63.0	0.0	0.3	267.0	0.2	327.0	24.0	4.4	0.0	96.0
Honey	40	1.8	0.0	0.0	7.3	0.0	54.5	2.5	196.4	18.2	0.0	0.0	83.6
Sugar	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Beef	125	36.9	0.0	0.0	0.0	0.2	15.0	1.5	472.5	28.8	5.5	0.0	105.0
Rice	50	3.8	0.7	0.0	0.2	0.1	5.1	0.4	65.0	14.0	0.1	0.0	2.2
Beans	50	2.9	3.3	15.8	6.0	0.3	12.0	0.5	105.0	9.0	0.1	0.0	2.0
Peas	35	2.1	2.6	23.6	5.2	0.1	12.3	0.6	52.5	7.4	0.1	0.0	0.7
Carrot	15	0.1	0.4	201.9	1.1	0.1	6.3	0.0	42.9	1.5	0.0	0.0	10.5
Green plums	100	0.8	2.3	20.0	6.0	0.5	12.5	0.5	236.5	11.5	0.0	0.0	0.5
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Bread	60	6.5	3.6	0.0	0.2	0.4	59.4	2.3	133.2	34.8	0.4	0.7	318.0
Total	2231	123.0	36.8	734.0	250.1	9.7	1104.7	20.6	4948.2	407.0	23.6	1.8	1327.0

Table 7. Nutritional composition of the Saturday Atlantic diet menu.

SATURDAY													
Food	Amount (g)	Protein (g)	Fiber (g)	Vit A (μg)	Vit C (mg)	Vit E (mg)	Ca (mg)	Fe (mg)	K (mg)	Mg (mg)	Sat. fat (g)	Ad. sugar (g)	Na (mg)
Milk	250	8.0	0.0	51.3	7.5	0.2	285.0	0.1	415.0	25.0	2.4	0.0	115.0
Strawberries	68	0.5	1.5	0.7	40.8	1.4	17.0	0.5	129.2	8.2	0.0	0.0	1.4
Prune	15	0.3	2.7	11.3	0.3	0.1	6.2	0.3	123.6	4.1	0.0	0.0	1.2
Bread	30	3.3	1.8	0.0	0.1	0.2	29.7	1.1	66.6	17.4	0.2	0.4	159.0
Kiwi	100	1.1	1.9	3.0	59.0	1.1	25.0	0.4	290.0	15.0	0.1	0.0	4.0
Potato	100	2.4	1.8	0.0	12.2	0.1	6.8	0.7	413.3	15.9	0.1	0.0	7.3
Cod	20	3.6	0.0	1.0	0.0	0.1	2.6	0.0	0.7	4.8	0.0	0.0	13.6
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Egg	60	7.5	0.0	114.0	0.0	0.7	34.2	1.1	78.0	7.2	1.9	0.0	84.0
Carrot	75	0.6	2.0	1009.5	5.3	0.4	31.5	0.2	214.5	7.5	0.0	0.0	52.5
Potato	70	1.7	1.3	0.0	8.5	0.0	4.8	0.5	289.3	11.1	0.0	0.0	5.1
Beans	65	3.8	4.2	20.6	7.8	0.3	15.6	0.7	136.5	11.7	0.1	0.0	2.6
Leek	40	0.6	1.1	33.2	7.2	0.3	12.4	0.4	102.4	4.4	0.0	0.0	4.8
Onion	20	0.2	0.4	0.0	1.4	0.1	5.1	0.1	32.4	0.8	0.0	0.0	0.6
Celery	20	0.2	0.4	19.0	1.6	0.0	10.4	0.1	61.0	2.8	0.0	0.0	22.0
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Garlic	50	2.0	0.6	0.0	7.0	0.1	8.9	0.6	223.0	12.1	0.0	0.0	9.5
Bread	60	6.5	3.6	0.0	0.2	0.4	59.4	2.3	133.2	34.8	0.4	0.7	318.0
Mandarin	120	1.0	2.3	127.2	42.0	0.3	43.2	0.4	192.0	13.2	0.0	0.0	2.4
Bread	40	4.4	2.4	0.0	0.1	0.3	39.6	1.5	88.8	23.2	0.3	0.5	212.0
Tomato	25	0.2	0.3	20.5	4.8	0.2	2.8	0.1	59.0	2.5	0.0	0.0	4.5
Cow cheese	30	6.7	0.0	102.0	0.0	0.2	229.2	0.1	27.7	8.2	5.4	0.0	126.1
Mushrooms	100	1.8	2.5	0.0	4.0	0.1	9.0	1.0	470.0	14.0	0.1	0.0	5.0
Onion	100	1.1	1.8	0.0	6.9	0.5	25.4	0.3	162.0	4.2	0.0	0.0	3.0
Chicken breast	75	16.7	0.0	0.0	2.8	0.2	10.0	0.7	158.4	11.8	1.4	0.0	39.6
Pasta	50	6.3	2.5	0.0	0.0	0.0	12.0	0.9	118.0	27.5	0.1	0.0	2.5
Orange juice	225	1.6	0.2	164.3	87.8	0.4	15.8	0.2	236.3	18.0	0.0	0.0	45.0
Olive oil	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Grapes	50	0.3	0.5	1.5	2.0	0.0	8.5	0.2	125.0	5.0	0.0	0.0	1.0
Bread	60	6.5	3.6	0.0	0.2	0.4	59.4	2.3	133.2	34.8	0.4	0.7	318.0
Total	1948	88.7	39.2	1679.8	309.2	11.4	1009.3	16.8	4479.0	345.2	18.1	2.3	1559.6

Table 8. Nutritional composition of the Sunday Atlantic diet menu.

SUNDAY													
Food	Amount (g)	Protein (g)	Fiber (g)	Vit A (µg)	Vit C (mg)	Vit E (mg)	Ca (mg)	Fe (mg)	K (mg)	Mg (mg)	Sat. fat (g)	Ad. sugar (g)	Na (mg)
Milk	250	8.0	0.0	51.3	7.5	0.2	285.0	0.1	415.0	25.0	2.4	0.0	115.0
Strawberries	40	4.3	3.5	0.0	0.0	0.1	25.2	1.3	108.0	35.6	0.2	0.5	256.0
Prune	160	0.8	1.9	16.0	32.0	0.2	19.2	0.8	400.0	22.4	0.0	0.0	3.2
Bread	150	2.6	0.0	23.7	0.8	0.1	82.5	0.1	135.0	12.0	1.8	0.0	34.5
Kiwi	8	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0
Potato	200	4.8	3.6	0.0	24.3	0.1	13.7	1.4	826.5	31.8	0.1	0.0	14.5
Cod	150	44.3	0.0	0.0	0.0	0.2	18.0	1.8	567.0	34.5	6.6	0.0	126.0
Olive oil	100	1.1	1.8	0.0	6.9	0.5	25.4	0.3	162.0	4.2	0.0	0.0	3.0
Egg	100	0.8	2.6	1346.0	7.0	0.5	42.0	0.3	286.0	10.0	0.1	0.0	70.0
Carrot	50	0.5	0.6	41.0	9.5	0.4	5.5	0.3	118.0	5.0	0.0	0.0	9.0
Potato	45	0.0	0.0	0.0	0.0	0.0	4.1	0.3	36.9	4.5	0.0	0.0	0.9
Beans	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Leek	100	0.9	1.4	59.1	88.4	78.0	11.8	0.5	205.8	13.2	0.0	0.0	3.9
Onion	10	0.0	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0	1.1	0.0	0.0
Celery	60	6.5	3.6	0.0	0.2	0.4	59.4	2.3	133.2	34.8	0.4	0.7	318.0
Olive oil	250	3.5	5.5	27.5	92.5	2.3	17.5	1.0	425.0	25.0	0.0	0.0	2.5
Garlic	175	3.2	4.4	0.0	7.0	0.2	15.8	1.8	568.8	24.5	0.1	0.0	8.8
Bread	75	3.0	0.9	0.0	10.5	0.1	13.4	0.9	334.5	18.1	0.0	0.0	14.3
Mandarin	60	7.5	0.0	114.0	0.0	0.7	34.2	1.1	78.0	7.2	1.9	0.0	84.0
Bread	60	7.5	3.0	0.0	0.0	0.0	14.4	1.1	141.6	33.0	0.1	0.0	3.0
Tomato	10	0.0	0.0	0.3	0.0	1.2	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Cow cheese	125	5.4	0.0	1.0	2.0	0.0	175.0	0.1	233.8	17.1	0.1	0.0	71.3
Mushrooms	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Onion	60	6.5	3.6	0.0	0.2	0.4	59.4	2.3	133.2	34.8	0.4	0.7	318.0
Chicken breast	2252	111.0	36.3	1680.2	288.7	92.2	921.4	17.5	5308.4	392.8	18.8	1.9	1455.8
Pasta	250	8.0	0.0	51.3	7.5	0.2	285.0	0.1	415.0	25.0	2.4	0.0	115.0
Orange juice	40	4.3	3.5	0.0	0.0	0.1	25.2	1.3	108.0	35.6	0.2	0.5	256.0
Olive oil	160	0.8	1.9	16.0	32.0	0.2	19.2	0.8	400.0	22.4	0.0	0.0	3.2
Grapes	150	2.6	0.0	23.7	0.8	0.1	82.5	0.1	135.0	12.0	1.8	0.0	34.5
Bread	8	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0
Total	200	4.8	3.6	0.0	24.3	0.1	13.7	1.4	826.5	31.8	0.1	0.0	14.5

Table 9. Origin of the foodstuffs and the corresponding distances for the transport stage.

Food	Origin	Distance (km)
Green plums	Spain	400
Prunes	United Kingdom	1950
Strawberries	Spain	400
Pumpkin	Spain	400
Kiwi	New Zealand	20400
Orange	Spain	400
Mandarins	Spain	400
Apple	Spain	400
Pear	Spain	400
Peach	Spain	400
Melon	Spain	400
Nectarine	Spain	400
Pineapple	Ghana	4900
Banana	Spain	400
Watermelon	Spain	400
White grapes	Spain	400
Orange juice	Spain	400
Figs	Spain	400
Raisins	United Kingdom	1950
Garlic	Iran	11670
Celery	Spain	400
Mushrooms	Spain	400
Cucumber	Switzerland	400
Onion	Spain	400
Carrot	Sweden	400
Boletus	Spain	400
Cabbage	Spain	400
Brussels sprouts	Spain	400
Cauliflower	Spain	400
Asparagus	Spain	400
Tomato	Spain	400
Lettuce	Spain	400
Potatoes	Spain	400
Green pepper	Spain	400

Table 9 (continued).

Food	Origin	Distance (km)
Red pepper	Spain	400
Padrón pepper	Spain	60
Leek	Spain	400
Radish	Spain	400
Beetroot	Spain	400
Beans	Spain	400
Peas	Spain	400
Rice	Spain	400
Coffee	Brazil	7860
Wholemeal cereals	Sweden	3400
Wholemeal biscuits	Sweden	3400
Pasta	Spain	400
Bread	Spain	400
Curd	Portugal*	400
Yogurt	Portugal*	400
Milk	Spain	400
Fresh cheese	Italy	400
Cow cheese	Galicia	60
Chicken	Portugal*	400
Pork	Galicia	60
Beef	Galicia	60
Tuna	Galicia	60
Cod	Sweden	3400
Cockles	Galicia	60
Calamari	Galicia	60
Octopus	Galicia	60
Cuttlefish	Galicia	60
Mackerel	Galicia	60
Sardines	Portugal*	400
Eggs	Spain	400
Olive Oil	Spain	400
Honey	United Kingdom	1950
Sugar	Island of Mauritius	11950

* Products from Portugal are considered to be transported from a similar distance than Spanish products

CHAPTER 4

Linking environmental sustainability and nutritional quality of the Atlantic diet recommendations and real consumption habits in Galicia (NW Spain)[7]

SUMMARY

Under the perspective that real consumption trends are often not in line with healthy recommendations, this chapter focuses on the study of the environmental and nutritional sustainability of two types of food consumption habits present in the northern Atlantic area of Spain (Galicia). The main objective is, therefore, to detect the existing deviations between the current Galician diet and the traditional and increasingly relevant recommended Atlantic diet, allowing verifying whether current consumption patterns ensure an optimal and sustainable nutritional profile. In this sense, following the approach of the Chapter 3, the carbon footprint from a Life Cycle Assessment perspective has been estimated as environmental indicator of both dietary patterns and, the nutritional quality has been determined by the Nutrient Rich Diet 9.3 index and the Health Score. The carbon footprint of the Galician diet is high compared to recommended diets such as the Atlantic or the Mediterranean. Comparing the two scenarios, the associated greenhouse gas emissions are about 15% higher for Galician Diet than for Atlantic diet, mainly due to the higher intake of beef and dairy products. On the other hand, nutritional quality is comparatively higher for Atlantic diet than for Galician Diet, associated with higher consumption of vegetables and fruits. An additional objective of this work has been to consider a sensitivity analysis to determine the effect of replacing beef with alternative sources. According to this research, it can be concluded that the real consumption pattern in Galicia is far from the recommended one, with worse environmental and nutritional quality. The promotion of social awareness policies to guide consumers in the choice a healthier and more environmentally sustainable dietary pattern should be advisable for regional decision-makers as well as for those who wish to promote adherence to the Atlantic diet in other regions and countries.

[7] Esteve-Llorens X.[a], Moreira M.T.[a], Feijoo G.[a], González-García S.[a] (2019c) Linking environmental sustainability and nutritional quality of the Atlantic diet recommendations and real consumption habits in Galicia (NWSpain). Sci Total Environ 683:71–79. ISSN: 0048-9697
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CHAPTER 4 - OUTLINE

4.1. INTRODUCTION

Numerous studies have been conducted in recent years to assess the environmental profile of the human diet (Castañé and Antón, 2017; Coelho et al., 2016; Pernollet et al., 2017; Van de Kamp et al., 2017) since dietary habits have shifted from traditional to the so-called "Western diet" based on the intake of animal based products in portions greater than recommended. As a result, the amount of GHG associated with a dietary choice varies significantly depending on the different products that makes it up (González-García et al., 2018), and largely depends on the efficiency of the production chain. On the road to healthier and more environmentally friendly dietary patterns (Van Dooren et al., 2014) governments from countries such as Sweden (Livsmedelsverket, 2015), United Kingdom (NHS, 2019), Germany (Gerlach et al., 2013) and Finland (Hyvää, 2015) have strengthened their efforts to set up committees to advise society on more sustainable dietary patterns. Among the recommended diets, the well-known Mediterranean diet (MD), traditionally present in Mediterranean countries (Spain, Italy, Greece, Croatia, Maghreb, Cyprus, and Portugal), receives special attention. It is considered a healthy diet by global organizations such as the World Health Organization and FAO (FAO and WHO, 2019). The MD is related to a low incidence of chronic diseases due mainly to the high intake of vegetables, fruits and whole grains (Castañé and Antón, 2017) and to the low intake of animal fats, with the moderate use of olive oil as a source of healthy fatty acids (Vaz Velho et al., 2016).

It is interesting to note how countries outside the traditional area of the MD have begun to promote the MD style (Van Dooren and Aiking, 2016; Wilson et al., 2013), as well as to create new dietary choices following that philosophy (e.g. the New Nordic diet) to achieve healthier consumption patterns (Donati et al., 2016; Hoek et al., 2017; Van Dooren and Aiking, 2016). As mentioned in Chapter 3, the Atlantic diet (AD) is another example of healthy diet in line with the MD, traditionally associated with the northwest of the Iberian Peninsula (Leis Trabazo et al., 2019)

Numerous studies available in the literature report that there are outstanding differences between the dietary recommendations established by health administrations and actual food consumption patterns (Blas et al., 2019). While the AD recommends a high consumption of fresh products such as vegetables and fruits, data on actual consumption habits indicate that this is not being met as it should be (Batlle-Bayer et al., 2019). Thus, there is a significant deviation between actual food consumption trends and the recommended dietary patterns, which implies an intensification of resources in the production chain. Current patterns of actual consumption are associated with increased intake of processed food and other resource-intensive products, such as those of animal origin or processed foods (Batlle-Bayer et al., 2019; Blas et al., 2019).

Therefore, the main goal of this chapter is to compare, from an environmental sustainability and nutritional quality perspective, the recommendations of the traditional

AD with the real consumption trends, considering Galicia as case study, as well as to provide an answer to the question whether current consumption patterns ensure an optimal nutritional profile. Finally, the level of concurrence between both dietary patterns was also determined by considering both the carbon footprint (CF), from a Life Cycle Assessment (LCA) approach associated with food production, as well as the nutritional quality. Regarding the latter, two different indexes have been proposed for analysis to improve robustness and consistency of results: The Nutrient Rich Diet 9.3 (NRD9.3) score, which takes into account the intake of certain valuable and harmful nutrients (Van Kernebeek et al., 2014) and the Health Score, which follows a similar approach for food groups (Van Dooren et al., 2014). Furthermore, from a practical point of view, the study will allow to identify the weak spots of the Galician diet (GD) from both a nutritional and environmental point of view and will serve as a guide for decision-makers to promote a consumption pattern in pursuit of the traditional diet.

4.2. MATERIALS AND METHODS

The comparative assessment of sustainability in terms of environmental impact and nutritional quality between two different dietary patterns related to the recommended AD and the actual consumption pattern has been carried out by estimating the CF as a representative environmental indicator, as well as by means of two nutritional quality indexes. A description of both perspectives is presented below.

4.2.1 CARBON FOOTPRINT METHODOLOGY

4.2.1.1. DESCRIPTION

In this chapter, the environmental sustainability of the two different dietary patterns in terms of their CF (i.e., GHG emissions) has been determined from an LCA approach, which systematically assesses the environmental burdens of each type of diet (ISO, 2006). The carbon footprint is selected as an environmental indicator due to its great relevance and widespread use in related studies of dietary patterns (Aleksandrowicz et al., 2016; Batlle-Bayer et al., 2019; González-García et al., 2020; Ritchie et al., 2018; Springmann et al., 2018) . In this case, the CF has been estimated considering the stages of production and transport to retailer and households, as well as the food loss and waste generated throughout the chain. In contrast with the Chapter 3, cooking activities at households has not been considered considering that differences between both scenarios can be negligible.

4.2.1.2. FUNCTIONAL UNIT

The selected functional unit to report the results corresponds to the daily amount of food eaten per person, that is, the individual daily diet. This functional unit allows the comparison between the scenarios proposed, as well as with other related studies available in the literature on environmental assessment of different types of daily diets

(Castañé and Antón, 2017; Pernollet et al., 2017; Werner et al., 2014) regardless of daily energy intake (i.e. kcal per capita and day).

4.2.1.3. SCOPE OF THE DIETARY SCENARIOS

The scope of the CF study for both scenarios considered a cradle-to-gate perspective (i.e., up to the gate of households). Thus, the systems analyzed included the stages of food production (i.e., production of the foodstuffs included in each daily diet) and transport activities (i.e., the distribution of the products from the factory, farm, or port to the corresponding retailers and from retailers to households) (see Figure 4.1). Therefore, storing at retailers and consumption stage at the households, which should include operations such as refrigeration at retailer, food preparation at home, refrigeration, and final waste disposal, were disregarded. The rationale behind their exclusion from the scope of the study is that these consumer activities should have a similar impact in both dietary scenarios, considered for the same region (Batlle-Bayer et al., 2019; Blas et al., 2019). Moreover, other studies (Berlin and Sund, 2010) established that the consumption stage could contribute up to 10% of the total life cycle GHG emissions when estimated considering the food consumed in a typical menu. However, regarding the estimation of GHG emissions from food cooking in or outside households, it should be necessary to have real information on the menus and the cooking method (i.e., boiling, frying, baking, …) considering information that is not available for the GD scenario (Sonesson et al., 2003). Thus, and taking in mind the mentioned studies, the exclusion of the consumption stage (i.e., food preparation) from the analysis could be justified. In addition, the exclusion of the stages mentioned also allows the results of this study to be compared with other relevant ones available in the literature (Castañé and Antón, 2017; Sáez-Almendros et al., 2013; Van Dooren et al., 2014).

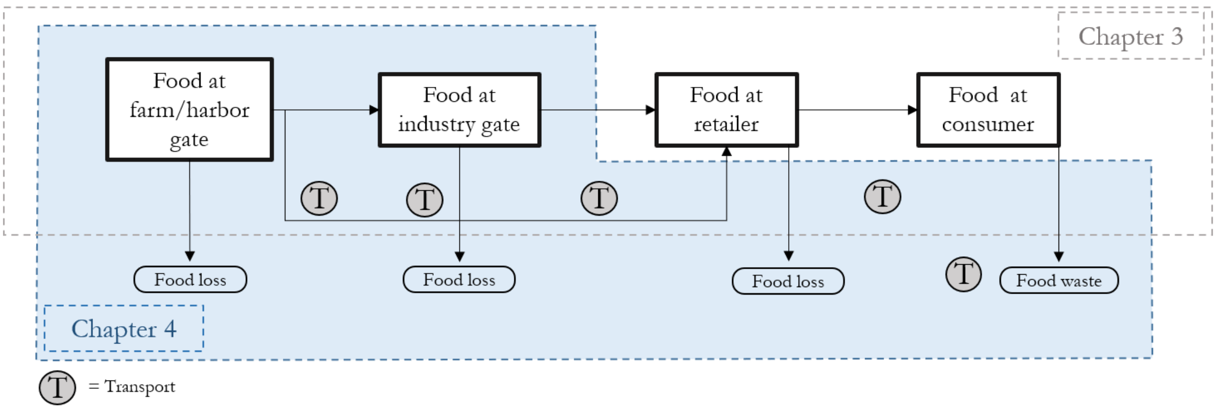

Figure 4.1. System boundaries considered in the analysis of the carbon footprint for the Chapter 4

Food losses and waste along the chain considered in both scenarios (see Figure 4.1) have been calculated based on García-Herrero et al. (2018). This estimation is based on the losses reported by FAO for European countries (Gustavsson et al., 2011). Bearing in mind that there is not detailed information on the loss percentage for pre-cooked food –

an important item in the current diet, the highest percentage reported by García-Herrero et al. (2018) for processed food (5%) has been assumed for this type of foodstuff as the worst case. Regarding the foodstuffs production stage, information on losses has been included in the corresponding background processes due to the consideration of the cradle-to-gate approach of the references consulted.

4.2.1.4. DESCRIPTION OF THE DIETARY PATTERNS

Galicia (NW Spain) has been historically characterized as the cradle of a wide selection of high quality food products, appellation of origin and organic farming with prestige beyond its borders (Xunta de Galicia, 2005). All these concepts are included within the AD model, fulfilling its basic characteristics such as abundance of seasonal, local and fresh products, high intake of plant-based products and seafood, as well as a moderate intake of animal-origin foodstuffs (Vaz Velho et al., 2016). Nevertheless, the current dietary choices of the Galician region may not be at all in line with these recommendations and with traditional patterns, which seem to vary in proportion and quantity of certain categories of foodstuffs. The spread of the occidental culture and the globalization of food consumption and production are behind these alternative choices; however, this trend is also observed in other dietary patterns such as the MD (MAPA, 2021).

Atlantic Diet – AD scenario

This scenario corresponds to the AD recommendations defined by the Health Department of the Xunta de Galicia (2013). The average food consumption from 7 daily-menus already analyzed in the Chapter 3 reported by Esteve-Llorens et al. (2019) have been taken into consideration. This research includes 67 foodstuffs grouped into 11 different categories (i.e., fruits, vegetables, legumes, grains, nuts, dairy products, eggs, meat, fish, sweets and oils/fats), all of which are recommended ingredients in the Atlantic food pyramid (Tojo and Leis, 2009) as well as in the traditional Galician gastronomy (Xunta de Galicia, 2013).. Therefore, the average daily intake of each food group (g·day^{-1}) has been considered for evaluation to facilitate the resulting comparison with the other scenarios proposed for analysis. Table 4.1 summarizes the daily intake of each food category per capita.

Galician Diet – GD scenario

The second scenario considered for analysis is based on the actual consumption patterns of the GD. The available surveys from the Galician Ministry of Health (SERGAS, 2007) have been analyzed to gather dietary information. The consulted study reports Galician eating habits in 2007 (last year updated) and it is based on data from 3,148 participants, both urban and rural residents. The nutritional analysis included 129 food-items according to the surveys (SERGAS, 2007). As a result, in addition to the food categories indicated in the AD scenario, an additional group of industrially processed foods has been included in the GD scenario which appears in the current consumption trends but is not included in the Atlantic dietary philosophy due to its low nutritional quality. The surveys were based on a dietary plan of 24 hours, conducted in two different seasons (Spring-Summer and Fall-Winter) to cover seasonal differences in the intake of some foodstuffs (e.g., broccoli, asparagus, peach, fig); in addition, a food consumption questionnaire was also carried out, supported by photographs of food servings to calculate the size of the portions eaten. The reported global food-items intakes have allowed the estimation of the apparent food consumption per capita a whole day (g·person^{-1}·day^{-1}) as shown in Table 4.1. Nevertheless, the aforementioned SERGAS survey (2007) only provides an average figure of the food consumed per person per day. Thus, variations between the different individuals surveyed cannot be appreciated. It is therefore important to take potential uncertainty into account when discussing the results.

Table 4.1. Daily amount (g) of each food category in the recommended Atlantic Diet (AD) and Galician Diet (GD) scenarios.

Food category	AD (g·person^{-1} ·day^{-1})	GD (g·person^{-1}·day^{-1})
Fruits	1024 ±275	439
Vegetables	633 ± 310	581
Legumes	29.3 ± 42	20.1
Grains	291 ± 37	319
Nuts	33 ± 15	5.0
Dairy	419 ± 122	472
Eggs	23.7 ± 30	26.2
Meat	91.9 ± 75	213
Seafood	195.7 ± 125	182
Processed food	0.00	88.1
Sweets	11.7 ± 22	15.5
Oil/fats	29.9 ± 3	23.6
TOTAL	2753 ± 207	2387
kcal	2100 ± 100	2381

4.2.1.5. DATA FOR CARBON FOOTPRINT ESTIMATION

After an extensive literature review, a total of 139 food products from 42 LCA studies have been included in the inventory data set to determine the CF scores of both diet scenarios, all of which have been analyzed from a cradle-to-gate perspective. In addition, these foodstuffs have been grouped into 12 representative food categories: fruits, vegetables, legumes, grains, nuts, dairy, eggs, meat, fish, processed food, sweets and oil/fats, attending to the AD pyramid (See Figure 3.1). In addition, due to their minor contribution on the daily diets (Castañé and Antón, 2017; Van Kernebeek et al., 2014), food condiments, soft drinks, infusions, coffee and alcoholic beverages have been left out of the scope of the research. On the other hand, certain products have been assimilated to others with similar production process and/or comparable nutritional characteristics due to the lack of data for the estimation of their environmental profiles. This is the case of chard (assimilated as lettuce), curd (as yogurt), semi-cured and cured cheese (as Galician cheese), leek (as onion), nectarine (as peach) and clams, oysters, and scallops (as mussels).

In terms of distribution, Euro 5 diesel freight lorries (>32 tons) have been chosen for transport activities from the factory/farm gate to retailers for Spanish products. Thus, distribution distances of 60 km and 400 km (on average) have been set for the foodstuffs supply from inside and outside Galicia, respectively, for all products included in the study. In this sense, considering the philosophy of the AD, it is assumed that most of the products are manufactured in Spanish territory, except certain foodstuffs that are imported such as pineapple, coffee, cod, or salmon (Ministerio de Industria, 2021) . In these cases, an average distance by ship and lorry from their country of origin to Galicia has been estimated. Regarding the transport from retailers to households, assumptions from Chapter 3 have been considered. Similarly, also for the estimation of the CF of transport activities, the Intergovernmental Panel on Climate Change (IPCC) characterization factors have been applied to quantify the equivalent CO_2 emissions to be added to those of the food production phase. Inventory data taken from the Ecoinvent ® v3.2 database (Wernet et al., 2016) have been considered for road and sea transport.

4.2.2. Nutritional quality estimation

The nutritional quality of a diet is as important as its environmental impact, whether or not it is considered a sustainable diet, and it is also an important concept in our time, when the growing trend towards a healthy lifestyle includes the consumption of nutrient-rich foods instead of high-calorie products (FAO and WHO, 2019). In this sense, the nutritional quality of both dietary scenarios (AD and GD) has been analyzed from an average daily menu perspective rather than from a single meal evaluation, which would not provide sufficient representative information on consumer habits (Van Kernebeek et al., 2014). In this case, the concept of daily menu is based on the average amount of each food-item consumed per person in a day.

In this chapter, two different nutritional indexes have been proposed for analysis, as they could be considered complementary. Firstly, the NRD9.3 index proposed by Van Kernebeek et al. (2014) was calculated. The full detailed explanation of all the elements involved in this index can be seen in section 2.3.2. of Chapter 2. On the other hand, the Health Score has also been proposed for estimation, which is based on certain parameters other than the nutrients mentioned above. This health index has been developed by Van Dooren et al. (2014), and as in the aforementioned index, detailed information about the parameters involved in calculating the Health Score and the corresponding equation are provided in section 2.3.3 of Chapter 2. Moreover, to contextualize the Health Score obtained for the AD and GD scenarios, the recommended reference values of the mentioned parameters reported by the WHO (Stankovic, 2015) have been considered. Additionally, the complete nutritional composition of the foodstuffs has been obtained from the Spanish Food Composition Database (AECOSAN, 2018). Finally, the estimated indexes for both dietary scenarios will be compared with other results available in the literature (Van Dooren and Aiking, 2016; Van Kernebeek et al., 2014) to rank their position in terms of nutritional quality.

4.3. RESULTS AND DISCUSSION

4.3.1. CARBON FOOTPRINT ASSESSMENT

The estimated CF for AD and GD is 4.53 kg CO_2 eq $\cdot$person$^{-1}\cdot$day^{-1} and 5.22 kg CO_2 eq person$^{-1}\cdot$day^{-1} respectively. The main factor responsible for the total GHG emissions is the foodstuffs production stage regardless of the scenario (i.e., 4.07 kg CO_2 eq $\cdot$person$^{-1}\cdot$day^{-1} and 4.80 kg CO_2 eq$\cdot$person$^{-1}\cdot$day^{-1} for AD and GD, respectively). The food production stage includes all the background processes related to agricultural and farming activities, as well as the corresponding industrial preparation activities if necessary (e.g., slaughterhouse, refrigeration, and packaging). Consequently, transport activities are responsible for around 10% of total GHG emissions in both scenarios, specifically, ~0.4 kg CO_2 eq$\cdot$person$^{-1}\cdot$day^{-1}. The rationale behind this fact is that, in the case of food patterns from the same geographical area, the foodstuffs come from the same sources in most cases and are transported over similar distances.

Figure 4.2 shows the individual CF per scenario for the food production phase, including the distribution by contributing food category. As it can be observed, livestock products (i.e., meat and dairy products) are the main contributor to the CF. Not only because they are some of the most consumed foods (Table 4.1) but also because they are the foods with the worst associated environmental profiles (Aleksandrowicz et al., 2016).

Focusing on meat products, both scenarios have a similar CF (i.e., 1.9 kg CO_2 eq and 2.2 kg CO_2 eq respectively for AD and GD), even though the amount of meat ingested is roughly double in the GD compared to AD as shown in Table 4.1. The rationale behind this result is associated with beef consumption, which is similar in both scenarios (66.9 g and 56.6 g respectively in AD and GD), being this type of meat the one with the worst associated environmental profile: 28.60 kg CO_2 eq$\cdot$kg^{-1} according to the average value reported by Clune et al. (2017). The CF associated with this amount of beef is 1.91 kg CO_2 eq and 1.62 kg CO_2 eq per person and day, being responsible for 42% and 31% of total GHG emissions in AD and GD, respectively. By comparison, the contribution to the total CF from meat consumption, considering other types of meat, is much lower than that from beef. In addition, it can be noted that beef alone accounts for about half of the total CF in AD, and about a third in the GD.

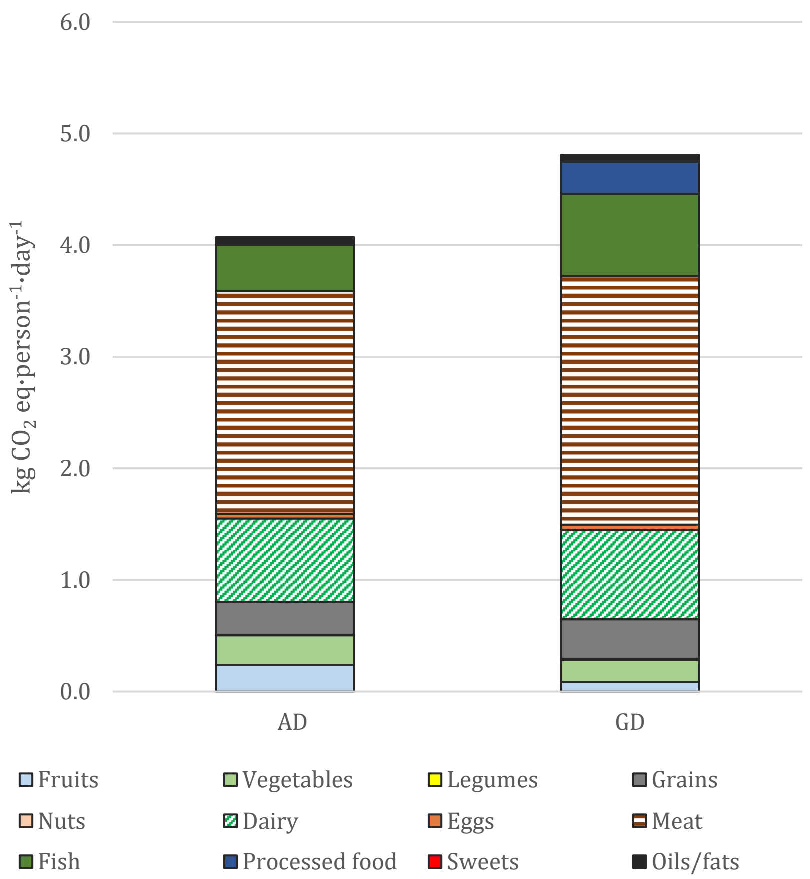

Figure 4.2. Distribution of food category contributions to the global carbon footprint. Acronyms: AD – Recommended Atlantic Diet scenario; GD – Galician Diet scenario.

For all other food products, dairy products also report a remarkable effect on the CF regardless the scenario under study. In AD, dairy products are responsible for 16% of the total CF. In the case of GD, their contribution is lightly lower (15%). This is a consequence of the notable intake of dairy products in the Galician region as shown in Table 4.1. The production of the seafood consumed is the third largest in terms of GHG emissions in both scenarios (see Figure 4.2). However, in this food category it is necessary to distinguish between AD and GD. Although the amount of seafood products is similar in both dietary patterns (195 g and 182 g respectively for AD and GD), the derived CF is almost twice as much in GD as in AD (0.73 and 0.41 kg CO_2 eq respectively). The rationale behind this surprising result is mainly explained by the consumption of certain species in the GD, with relatively high GHG emission factors (e.g., salmon, hake, flatfish, prawns, and canned tuna), which were not considered within the designed menus of AD. As a result, seafood products account for about 14% of the total CF for the GD, and about 9% for AD.

Moreover, it is interesting to note the contribution of the processed food category in the case of GD. As mentioned above, this category only appears in GD, as it includes products not recommended by the health authorities due to their low nutritional quality (Xunta de Galicia, 2013). However, they are present in the current consumption trends.

In this sense, the consumption of processed foods represents around 6% (0.29 kg CO_2 eq) of the total CF in GD, which is a higher ratio than that associated with other ingredients such as vegetables and fruits (≈4% and ≈2% respectively), which are considered basic foods in the diet. Finally, in terms the contribution to the CF score of food losses along the food supply chain, its relevance to the environmental footprint can be highlighted since food losses represent around 14% of the total CF for both scenarios (around 0.7 kg CO_2 eq). Therefore, attention should be paid to this hotspot.

4.3.2. Comparing the nutritional quality of AD and GD scenarios

Regarding the NRD9.3 index, the results estimated for AD and GD are 474 and 242, respectively, as shown in Table 4.2. The amount of each nutrient ingested to limit and promote is also depicted in the table, as well as its recommended daily intake value (RDV). It is important to note that when the RDV outcomes fall between two values, an average value has been considered in the estimation.

As can be seen, the intake amount of many nutrients is higher than the RDV in both scenarios. On the other hand, comparing the ingestion values corresponding to the nutrients to encourage, their intake is higher for most nutrients in AD than in GD mainly due to the large consumption of fruits and vegetables (see Table 4.1). However, in terms of protein and calcium, the situation is reversed. The higher intake of protein in GD (2.5 times higher than the RDV) is related to the remarkable consumption of meat, considerably higher than the recommended values (see Table 4.1). The higher intake of dairy products in GD consequently increases the amount of calcium ingested, being 0.2 times higher than the RDV.

When comparing the intake of nutrients to limit, saturated fat, free sugars and sodium are ingested in higher amounts in the GD than in the AD, which is mainly attributed to the consumption of processed foods (AECOSAN, 2018). In this regard, it is important to mention that in AD, the intake of all limiting nutrients is below the RDV. In contrast, the intake of saturated fat and sodium in the GD is considerably higher than the recommended values. The intake of added free is much higher than the RDV for the GD, mainly due to the intake of processed foods and sweets. Considering that sodium is the leading cause of death due to an inadequate diet, followed by a low intake of fiber and fruits (Afshin et al., 2017), emphasis is placed on avoiding excessive consumption of this element.

Table 4.2. Nutrient Rich Diet 9.3 (NRD9.3) index for both Recommended Atlantic Diet (AD) and Galician Diet (GD) and Recommended Daily Value (RDV) for each nutrient considered in the index.

Nutrient	Units	RDV	AD	GD
Protein	g	50	101	133
Fiber	g	25	39.9	36.8
Vit A	µg	700-3000	1448	967
Vit C	mg	60-2000	320	195
Vit E	mg	20-1000	23.0	11.7
Ca	mg	1000-2500	1083	1182
Fe	mg	18-45	33.0	18.5
K	mg	3500	4938	4151
Mg	mg	400	435	364
Saturated fats	g	20	19.3	35.2
Free sugars	g	50	117	101.1
Na	mg	1500-2400	1449	2537
NRD9.3			474	242

The Health Scores for the AD and GD scenarios are shown in Table 4.3, as well as the required reference values for each parameter (Equation 4.2). As previously reported, the Health Score is the result of the ratio between the reference intake values considered for vegetables, fruits, total fatty acids, free sugars, fiber, sodium, and energy and those for actual intake in both scenarios.

Table 4.3. Health Score results for both Recommended Atlantic Diet (AD) and Galician Diet (GD) scenarios.

Indicator	Units	Reference value	AD	GD
Vegetables	g	200	462	424
Fruit	g	200	747	321
Total fatty acids	%	30	31.8	31.9
Free sugars	%	10	22.3	23.5
Fiber	g	30.0	39.9	36.8
Sodium	g	6.0	1.4	3.1
Energy	kcal	2100	2100	2381
Health Score		100	198	115

As can be seen, the amount of vegetables and fruits consumed in both scenarios is higher than the reference values set by WHO (WHO, 2003). In this sense, it is important to note that the intake of vegetables is more than double the reference quantity regardless of the scenario analyzed, and almost three times higher for the intake of fruits for AD. Even the quantity of fruit consumed in the GD is 50% higher than the reference value (321 g versus 200 g). The justification for these differences is associated with the high availability of vegetables and fruits in the Atlantic region throughout the year, as well as the cultural culinary tradition of the region. In terms of fiber intake, the amount consumed in both scenarios is also above the reference value (30 g), an increase of 33% and 23% respectively for AD and GD. As beneficial parameters, a higher intake of vegetables, fruits and fiber leads to better nutritional quality and, consequently, a higher Health Score. Considering the percentage of energy obtained from total fatty acids and free sugars, it should be mentioned that the proportions are above the reference value. While it is only 2% higher for total fatty acids, the percentage of energy from sugars far exceeds the recommended value, which is evidenced by a clear negative effect on the final Health Score. However, it is important to point out that the high intake of free sugars is directly related to high fruit consumption. On the other hand, the daily intake of sodium is lower than the recommended dose (6 g), at values around 75% and 50% lower in AD and DG, respectively.

Energy intake in both scenarios varies slightly from the 2,000 kcal set by WHO (WHO, 2012). An increase in calorie intake is not considered advisable and has a negative impact on the health benefit score. With all these data reported, the Health Score has been estimated for both scenarios according to Equation 4.2.

The values obtained for both scenarios are 198 points and 115 points respectively for AD and GD (Table 4.3). Despite this outstanding difference, both scores are above the WHO benchmark (i.e., 100 points). Comparing the AD and DG scores, the reason for the large difference in Health Scores is directly associated with fruit intake, as no notable differences in the remaining parameters can be identified. Otherwise, this practice also influences the fact that the health gain values in GD are above the reference value, mainly due to higher consumption of vegetables and fruits. Furthermore, it should be borne in mind that due to non-excessive energy intake (Table 4.3), the Health Score is not affected by this factor which on the contrary, would significantly penalize the nutritional quality.

4.3.3. BENCHMARKING ENVIRONMENTAL AND HEALTH SCORES

Taking into account the results obtained in terms of nutritional and CF indexes, it is necessary to establish a relationship between them and those of the different studies available in the literature (Van Dooren et al., 2014; Van Dooren and Aiking, 2016). The Health Score for AD (198) is above the values found in the literature for other well-positioned dietary options from environmental and health approaches such as the MD, vegan (VD), vegetarian (VGD) and semi-vegetarian (SVGD) diets as can be seen in Figure 4.3. On the other hand, the Health Score achieved for GD (114) is above the reference value (100) as mentioned above and is consistent with those identified for other dietary patterns (Figure 4.3), and even better than VGD or SVGD.

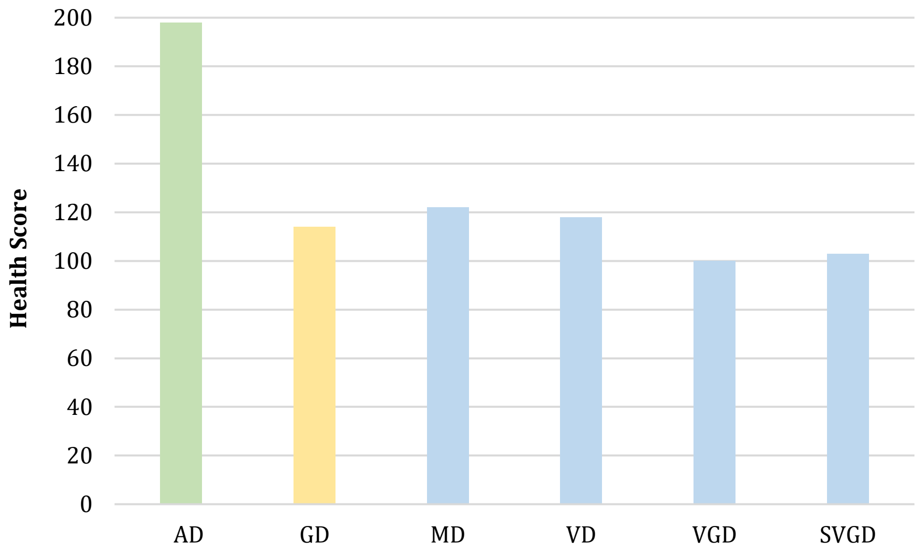

Figure 4.3. Comparison in terms of Health Score of AD and GD with alternative healthy diets available in literature. Acronyms: MD - Mediterranean diet; VD - Vegan diet; VGD - Vegetarian diet; SVGD - Semi-Vegetarian diet.

To establish a relationship between the nutritional quality and the CF, Table 4.4 details the NRD9.3 and CF scores of both scenarios under study and the studies available in the literature; the Health Score has not been included in this table due to lack of information to perform the estimation of this index for these diets. Regarding the NRD9.3 values, AD and GD obtain a score in line with those of these diets that use the same RDV (Castañé and Antón, 2017). As it can be seen in Table 4.4, the AD score reports a higher nutritional quality than others in the literature. On the other hand, the nutritional score for GD is lower than most of the values cited (e.g., Mediterranean, and Healthy diets). Nevertheless, it is necessary to keep in mind that this is a scenario based on real consumption trends and it is not a one based on recommendations such as the other studies mentioned in the literature (Castañé and Antón, 2017; Pathak et al., 2010; Risku Norja et al., 2009; Saxe et al., 2012; Van Dooren et al., 2014). It means that certain type of foods of lower nutritional quality, such as processed food and sweets, are included.

Considering the CF for RAD and GD and comparing these values with others reported in the literature, our scenarios involve relatively high CF scores (i.e., 4.53 and 5.22 kg CO_2 eq·pers^{-1}·day^{-1} respectively for AD and GD) mainly due to the huge consumption of beef as mentioned above. In view of the results, it is important to refer to the fact that all the dietary patterns mentioned, except the current Spanish dietary pattern of Sáez-Almendros et al. (2013), the Danish dietary pattern of Saxe et al., (2012) and GD, are diets based on recommendations, generally leading to lower CF outcomes. However, attention should be paid to the system boundaries considered since waste production and distribution to households have been included in our study, these stages being responsible for 24% of total CF. In this sense, food distribution and waste are relevant hotspots that significantly increase the CF value and have not been considered in the abovementioned studies. As can be seen, nutritional quality and CF are not always inversely proportional parameters when comparing diets from different studies; however, there is a trend that links both. In this sense, a higher nutritional quality usually translates into a lower CF, as is also observed for the MD and VD diets in Castañé and Antón (2017). Considering these interactions, it is important to stand out that the variation on both the nutritional quality and the CF is always related to the products of animal origin (i.e., meat and dairy).

Table 4.4. Summary of NRD9.3 and Carbon Footprint (CF) indexes regarding AD (Atlantic diet), GD (Galician diet) and other diets available in literature.

	NRD9.3	CF (kg CO_2 eq·person^{-1}·day^{-1})
AD	474	4.53
GD	242	5.22
Mediterranean diet (Castañé and Antón, 2017)	389	2.86
Vegan diet (Castañé and Antón, 2017)	469	1.86
Mediterranean diet (Sáez-Almendros et al., 2013)	-*	2.19
Spanish current diet (Sáez-Almendros et al., 2013)	-*	4.39
Vegan diet (Castañé and Antón, 2017)	469	1.86
Vegetarian diet (Pathak et al., 2010)	424	0.58
Healthy diet (Risku Norja et al., 2009)	382	3.84
Vegan diet (Risku Norja et al., 2009)	442	2.47
Vegetarian diet (Van Dooren et al., 2014)	-*	3.2
Danish dietary pattern (Saxe et al., 2012)	112	5.52

*Nutritional information not available.

4.3.4. SENSITIVITY ANALYSIS OF DIETS SUSTAINABILITY

As mentioned above, beef meat is the main source of GHG emissions for both scenarios under study. For this reason, a sensitivity analysis is proposed to determine the effect of the substitution of this type of meat by other types of foods that imply lower GHG emissions and a similar contribution of protein in both diets, as summarized in Table 4.5, without significantly affecting energy intake (kcal per day). In this sense, six protein-rich foods have been selected: Two alternative types of meat (pork and chicken) have been selected as alternatives to beef, taking into account that they are the second (pork) and third (chicken) most consumed meats in Galicia (MAPA, 2021); two legumes (lentils and peas) have also selected for analysis taking into account the recommendations from Jungbluth at al. (2016), which advise the consumption of vegetable proteins as opposed to animal proteins (Jungbluth et al., 2016); finally a couple of fish products (hake and tuna) have been considered, considering the priority of fish consumption in the AD (Álvarez and Peláez, 2018).

Table 4.5. Sensitivity analysis of Carbon Footprint (CF) and NRD9.3 results when substituting beef-meat in AD and GD scenarios by alternative foodstuffs (meat, legumes, and fish).

	AD		GD	
Scenario	**CF (kg CO_2 eq·person^{-1}·day^{-1})**	**NRD9.3**	**CF (kg CO_2 eq·person^{-1}·day^{-1})**	**NRD9.3**
Beef-meat	4.53	474	5.22	242
		Meat		
Pork	2.81	512	3.79	245
Chicken	2.84	515	3.77	247
		Legumes		
Lentils	2.63	513	3.67	269
Peas	2.62	523	3.62	266
		Fish		
Hake	3.08	512	3.96	271
Tuna	2.72	515	3.69	272

As regards the simulations carried out for AD and GD, it is noted that the removal of beef meat in both cases results in a drastic reduction in the CF. In this sense, the highest variation in both the CF and NRD9.3 scores occurs when beef is replaced by legumes, with a reduction in the CF of about 40% and 30% for AD and GD respectively, and an improvement in the nutritional quality of about 10% in both situations. On the other hand, the consideration of alternative meats reduces the CF by 40% and 30% in AD and GD respectively, resulting in an improvement of the nutritional quality in both scenarios, around 10% for AD and 2% for GD. Finally, the alternative of fish products also leads to an improvement in the nutritional quality, in this case the highest one in the GD. Regarding the CF score, it is also reduced in both scenarios although the reduction is lower if hake is considered than tuna, which has a moderately high GHG emission factor. It could therefore be reported that the replacement of beef with alternative food products would be a beneficial measure both environmentally and nutritionally.

Analysis of data quality

In terms of data quality, CF is selected as an environmental indicator. In this regard, the variability of LCA data for each product should be taken into account, e.g., for beef meat the carbon footprint ranges from 9.3 kg CO_2 eq·kg^{-1} for organic farming (Solid Forest, 2011) to 28.73 kg CO_2 eq·kg^{-1} for conventional farming (Clune et al., 2017). Thus, most conservative figures have been considered and the results have been carefully discussed. Furthermore, the beef meat has been identified as a hotspot regarding the results for CF, which could be identified as an opportunity by LCA practitioners to improve their production processes (e.g., technological adaptation at the farm level in order to minimize methane emissions from either enteric fermentation or manure management)(Hyland et al., 2017). Moreover, additional environmental indicators, such as water footprint or land occupation, should be taken into consideration to obtain a more complete environmental profile.

Additionally, regarding the source of actual food consumption figures for the GD scenario, data from a survey conducted in 2007 has been used, as previously mentioned, due to the lack of more updated real representative data. Thus, this survey is the most recent one for Galicia and the most detailed. However, consumption habits evolve and consequently the CF and nutritional quality. Therefore, efforts should be conducted in the design of a food frequency consumption questionnaire to be supplied to the Galician population for the handling of real parameters.

4.4. CONCLUSIONS

The outcomes of this chapter prove that there is a deviation between actual consumption patterns and diets based on health recommendations, both from an environmental and nutritional point of view. Thus, in the specific case of Galicia, the current dietary pattern obtains much lower scores in nutritional indexes and a higher CF than the recommendations from the traditional AD. Therefore, a change in the current trends of food consumption towards the recommendations of the Atlantic pyramid would be beneficial. In this sense, as weak spots in the GD (excessive sodium intake), processed and pre-cooked foods should be left aside, as they are the ones with the worst nutritional quality. However, it has also been proven that both the nutritional and environmental quality of the two studied scenarios can be improved by replacing beef with a more sustainable source of protein, taking as reference the methodology used in this study. In this sense, it is advisable to provide more proteins of vegetable origin than those of animal origin, with legumes being the best possible substitute.

The results can be useful for regional policy makers and sanitary authorities to act on the hotspots that cause the greatest loss of nutritional quality and the resulting increased carbon footprint. In the same way, they can be also extended to other regions or countries interested in promoting adherence to the AD.

Further research should be based on the design of new variants for the AD, focusing on improving environmental quality without affecting its nutritional quality; the changes should be made by replacing foods with a higher environmental impact with more sustainable ones, included in the traditional foods of the AD. In addition, considering the concept of sustainable diet, future research should include other relevant environmental impacts that are also significant in studies related to food production, such as the water footprint, and socio-economic indicators related to the affordability of diets.

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CHAPTER 5

Evaluating the Portuguese diet in the pursuit of a lower carbon and healthier consumption pattern[8]

SUMMARY

There is growing concern about the nutritional quality and the environmental impact of the food we eat. Although the population is increasingly aware of adhering to diets that meet these requirements, the reality is that current dietary patterns deviate greatly from these recommendations. In the case of Portugal, the Mediterranean and Atlantic diets have traditionally coexisted in the country, but it is predictable that current consumption patterns do not conform to them. Accordingly, the present chapter has a dual objective, taking the Portuguese dietary pattern as a case study. First, sustainability in terms of environmental and health impacts is monitored over a nine-year period (2008-2016), including the stages of production, distribution, and household activities. Secondly, an example of alternative diet is proposed in the pursuit of a more sustainable dietary pattern. The carbon footprint from a life cycle perspective has been selected for the environmental impact assessment and the Nutrient Rich Diet 9.3 index for the analysis of the nutritional quality. An average value of 4.20 kg CO_2 eq·inhabitant^{-1}·day^{-1} is reported for the Portuguese diet for the period under study. Regarding the alternative diet proposal, it leads to an increase of the nutritional quality of around 67%, and a reduction of the carbon footprint by approximately 25%, approaching the values of recommended diets such as the Mediterranean and the Atlantic ones. This research can serve as a reference for decision-makers, as well as to provide consumers with a clearer picture of what should be included in their food basket.

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CHAPTER 5 - OUTLINE

5.1. INTRODUCTION

Promoting healthy nutrition and sustainable food systems is a central task of our time at the confluence of population growth and economic development. The United Nations 2030 Agenda for Sustainable Development includes the adoption of urgent actions to mitigate climate change and its impacts, paying attention to human consumption patterns and their influence on the environment (United Nations, 2019). In this sense, there is a widespread global interest in adopting sustainable diets, with a primary focus on reducing GHG emissions associated with dietary choices (Aleksandrowicz et al., 2016; Springmann et al., 2018b). According to Food and Agriculture Organization of the United Nations (FAO), sustainable diets are those that have a low environmental impact, contribute to food safety and quality for present and future generations and are affordable and culturally acceptable (FAO and WHO, 2019). Considering that current diets represent a threat to public health (Esteve-Llorens et al., 2021; S. González-García et al., 2018), as they are based mainly on a high intake of animal-origin products and processed foods (Sara González-García et al., 2018), the concept of sustainable diet represents an opportunity to make fruitful progress in the commitment towards sustainable development and to guarantee food and nutrition security. The promotion of the traditional and well-known Mediterranean diet also outside its primary countries is an example of the necessary modification of the diets (Van Dooren et al., 2014). This diet is presented as an example of sustainable diet in which nutrition, biodiversity, local food production and culture are deeply interconnected (Castañé and Antón, 2017).

Portugal presents a valuable case study for evaluating the environmental footprint and nutritional values of different diets. From a dietary perspective, Portugal can be traditionally divided in two distinct regions: a marked Atlantic identity in the North (Vaz Velho et al., 2016) and a more Mediterranean character in the South. A common denominator in both regions is the Atlantic Ocean, an important source of seafood and one of the essential resources of the Portuguese food identity (Valagão, 2014) since Portugal is the third largest fish consumer per capita in the world after Iceland and Japan (Vaz Velho and Rodrigues, 2015). The Atlantic diet, which is considered an example of a healthy and sustainable diet (Esteve-Llorens et al., 2020; González-García et al., 2020; Leis Trabazo et al., 2019), differs from the widely recommended Mediterranean diet. Traditionally widespread in Northern Portugal and Galicia (North-western Spain), the Atlantic diet has characteristics of the Mediterranean (abundant consumption of vegetables, fruits and olive oil as the main source of fatty acids), but higher intake of fish, meat, legumes and especially, potatoes (Guallar-Castillón et al., 2013; Leis Trabazo et al., 2019), less use of complex cooking methods and higher priority on seasonal and fresh food (Vaz Velho et al., 2016). Taking the Atlantic diet into account, overall Portuguese consumption patterns as reported in the national statistical databases[9] differ from the recommendations, both in terms of quantities and proportions of food types. These

[9] http://www.ine.pt

deviations would predictably affect not only the nutritional quality of the Portuguese diet, but also the associated environmental pressure.

Accordingly, the main objectives of Chapter 5 are to measure the environmental impact and nutritional quality of the actual Portuguese dietary pattern and to propose changes needed to make the diet more sustainable. As far as the authors know, no previous studies have addressed these issues for the Portuguese population, so the outcomes may be useful not only for consumers but also for policy makers to achieve a more sustainable food consumption within the framework of the United Nations 2030 Agenda for Sustainable Development. Following the same approach as in Chapters 3 and 4, the environmental impact of dietary patterns is determined based on the Carbon Footprint (CF) considering a Life Cycle Assessment (LCA) perspective. Accordingly, the nutritional quality is evaluated by estimating the Nutrient Rich Diet 9.3 (NRD9.3) score as the base indicator, although a discussion about alternative scores is also carried out. Finally, the proposal of an example of alternative diet is performed following the recommendations from the EAT-Lancet Commission planetary health diet, with the intention of achieving the desired improvement in the CF and nutritional quality of the Portuguese diet.

5.2. MATERIALS AND METHODS

To achieve the dual objective proposed in this research, Portuguese dietary patterns have been compiled for the 2008-2016 period by using the Portuguese Food Balance database, computing for each year the corresponding CF and NRD9.3 values.

5.2.1. PORTUGUESE FOOD BALANCE

The study of the Portuguese diet has been carried out on the basis of the Portuguese food balance surveys, conducted by the Portuguese National Institute of Statistics for the period 2008-2016 (INE, 2014, 2017). The large amount of data that is given, provides information on the quantities of the different food categories daily available for consumption (i.e., fruits, vegetables, legumes, grains, nuts, dairy, eggs, meat, seafood, sweets, and fats). These surveys are an analytical instrument that measures food consumption from a supply point of view without considering food losses. Hence, to obtain more accurate data on food consumption, the reported food intake values have been recalculated considering the food losses along the supply chain. To do so, the corresponding percentages of losses for each food category have been subtracted, according to the information provided by the Portuguese government (Baptista et al., 2012; Governo de Portugal, 2014). The quantities vary considerably between the raw data reported by INE and those used in the present research (from 2 kg food·inhabitant^{-1}·day^{-1} to 1.6 kg food·inhabitant^{-1}·day^{-1} and from ≈ 3600 kcal·inhabitant^{-1}·day^{-1} to 3000 kcal·inhabitant^{-1}·day^{-1}).

Within the diverse food categories, a total of 43 different foodstuffs have been included in the study (see Appendix A). The composition at the level of macronutrients (i.e., protein, fatty acids, and carbohydrates) and micronutrients (i.e., vitamins and minerals) is provided in the surveys. All this information is used to estimate both the CF (considering the amount of each product consumed per inhabitant and day) and the nutritional quality (considering the daily intake of micro and macronutrients per inhabitant). In addition, the energy content of the food consumed is considered for the proposal of an example of alternative diet, with lower calorie ingestion but better environmental and nutritional profiles.

5.2.2. NUTRITIONAL QUALITY ASSESSMENT

In the same way as Chapter 3 and 4, the NRD9.3 index, proposed by Van Kernebeek et al., (2014), has been selected for the estimation of the nutritional quality of the Portuguese food profile. For this purpose, the nutritional information from Portuguese food balance surveys is used to obtain the daily per capita nutrient intake. It is considered as a reference indicator, and it has been widely used in nutritional quality and sustainability studies of diets (Batlle-Bayer et al., 2019; Castañé and Antón, 2017; Van Kernebeek et al., 2014). The detailed description of the index can be found in Section 2.3.2 of Chapter 2. The recommended reference values for the daily intake of each nutrient are in this case those indicated by the Codex Alimentarius provided by FAO and the World Health Organization (WHO) (FAO/WHO, 2017). Otherwise, ss previously mentioned, the surveys from the National Institute of Statistics provide the necessary information on micro and macronutrients corresponding to the Portuguese dietary patterns, which are used to carry out these estimations. This nutrient density index has been selected as the base score in this study although there are other nutritional indexes available in the literature that take into consideration additional nutrients (e.g., Vitamin D, folate and phosphorous), energy intake or even the ingested amount of specific groups of food such as fish, vegetables and fruits (Röös et al., 2015; Van Dooren et al., 2017, 2014). Therefore, to identify possible differences in the conclusions, the Health Score index proposed by van Dooren et al., (2014) is analyzed in the discussion section as a sensitivity analysis to determine how the nutritional quality of the dietary patterns vary depending on the nutritional index used.

5.2.3. CARBON FOOTPRINT ASSESSMENT

In line with previous chapters, the CF value from a LCA perspective has also been considered as the environmental indicator due to its special importance in the evaluation of environmental pressures of diets (Sara González-García et al., 2018). The CF associated with the Portuguese diet in the 2008-2016 period has been quantified considering a cradle-to-mouth perspective as in Chapter 3. Thus, the life cycle of the diet under study has been divided into three main stages (see Figure 5.1) that are production, distribution (i.e., transport from industry to retailers and from retailer to households), and household activities (including cooking and storage). It should be noted that the stages of distribution and household activities have been considered for the analysis of the Portuguese diet to allow the comparison with other studies since their contribution may be relevant. Similarly, taking as reference the results from Chapter 3, household activities can contribute up to 10% to the total life cycle GHG emissions, and together with distribution activities, up to 22% of the CF in the Atlantic diet.

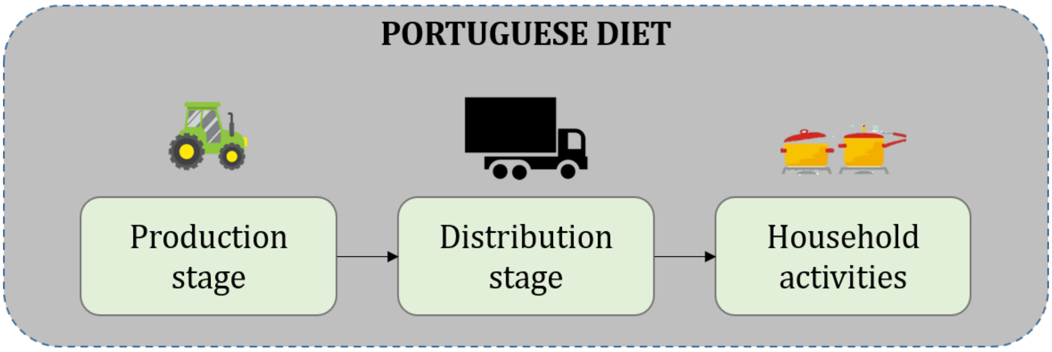

Figure 5.1. System boundaries considered for the analysis of both the Portuguese dietary patterns in the 2008-2016 period.

The functional unit selected in this study is the daily amount of food ingested per inhabitant in line with Chapter 4, without considering any determined amount of energy supplied (i.e., kcal·inhabitant^{-1}·day^{-1}). It allows the comparison between the Portuguese food profile and those from Chapter 4 and other relevant studies (Arrieta and González, 2018; Castañé and Antón, 2017; Esteve-Llorens et al., 2019b; Sara González-García et al., 2018). Regarding the data handled to estimate the CF, a total of 22 LCA studies have been consulted to obtain the CF value of the 43 foodstuffs included in the dietary patterns reported by the National Institute of Statistics (INE, 2014, 2017). Alcoholic and non-alcoholic beverages have also not been included in the scope of the study in line with the previous chapters. For the distribution stage, an average distance of 233 km has been taken into account for the road transport of the different foodstuffs from the farm/factory gate to retailers according to information from the National Institute of Statistics (INE, 2017). As in previous chapters, Euro 5 diesel freight lorries (>32 tons) have been considered for this purpose. Regarding the distribution from retailers to household, due to the lack of specific data for Portuguese consumers, the information for this step has been taken from Muñoz et al. (2010). Finally, the same frequency of purchase per week and kilometers travelled by car to the retailer as in Chapter 3 have been considered (i.e., about 20% of consumers use the car for shopping, considering an average road transport distance of 10 km travelled once a week).

Additionally, there are some unknown foodstuffs classified as "others" by the surveys consulted. In these cases, an average CF of the foods included in the corresponding category has been considered (i.e., vegetables, fruits, meat, dairy, and fats). Finally, the stage of household activities includes home storage in refrigerators (when necessary) and cooking. In terms of refrigeration, the energy consumption reported in Chapter 3 associated with the use of a combined refrigerator and freezer in households has been considered. Concerning the cooking activities, the absence of defined menus implies that a methodology cannot be used to determine the energy needed to prepare each meal. Hence, the figures from Chapter 3 and Castañe and Antón (2017) have been selected keeping in mind the cooking processes of the Atlantic and Mediterranean diets and their occurrence in the country. This leads to an estimated energy consumption of 0.83 kWh·inhabitant^{-1}·day^{-1}. Emissions from energy consumption, both storage and cooking per inhabitant and year are therefore fixed values considered for the 2008-2016 period.

5.2.4. ALTERNATIVE DIET PROPOSAL

The proposed approach towards a healthier and lower carbon diet comes mainly from the need to achieve a reduction in the high calorie intake characteristic of the current Portuguese diet, detected in the consulted surveys from the National Institute of Statistics (INE , 2014, 2017). In this way, high calorie diets are related to lower nutritional quality and higher GHG emissions, as reported by Doro and Réquillart (2020). To achieve this goal, the guidelines from the novel study from the EAT-lancet Commission on Food, Planet and Health are taken as reference (Springmann et al., 2018b, 2018a; Willett et al., 2018). It is focused on the changes that should be made to feed the growing world population (near 10 billion people by 2050) in a healthy and environmentally friendly way. The design of a sustainable planetary diet is among the measures proposed in the EAT-Lancet Commission report and these guidelines are selected as reference recommendations. By following these recommendations, the objective is to propose specific changes in the current Portuguese diet and achieve an example of more sustainable dietary pattern, that approaches to the Planetary Health Diet. Having in mind the food intake, measures should focus on reducing the intake of some foodstuffs (i.e., fats, sweets, meat, and grains) and increasing the amount of other healthier ones, such as fruits, legumes, and nuts.

5.3 RESULTS AND DISCUSSION

The first part of this section is focused on the presentation and analysis of the CF and nutritional quality corresponding to the Portuguese dietary pattern over the 2008-2016 period. Secondly, an example of alternative diet is designed, and the corresponding environmental and nutritional outcomes are explained in detail.

5.3.1. MONITORING OF THE DIETARY HABITS IN PORTUGAL (2008-2016)

As for the CF of the results of the Portuguese diet, an average value of 4.20 kg CO_2 eq·inhabitant^{-1}·day^{-1} is obtained for the period under study. As mentioned above, the stages of production, distribution and household activities are included in the scope to be able to compare this CF with those from other studies with the same system boundaries and different dietary habits. Production stage presents in general the highest GHG emissions (80%), followed by household activities (14%) and distribution (6%) stages. It is an usual distribution in CF estimations of diets, as reported in Chapters 3 and 4 and other similar studies (Batlle-Bayer et al., 2019; González-García et al., 2020). Keeping in mind the average CF of the 2008-2016 period, livestock products and grains account for about 65% of the total CF. When comparing the CF of the different years within the scope, the values range from 4.09 kg CO_2 eq·inhabitant^{-1}·day^{-1} in 2011 to 4.30 kg CO_2 eq·inhabitant^{-1}·day^{-1} in 2016 (see Figure 5.2). Although the differences between the CFs of the different years are not very high (±5% of the average value), it is possible to detect a decreasing trend in the central years of the period and a subsequent growth up to the highest emission levels. In addition, the CF values follow the same trend as the energy intake of the dietary pattern.

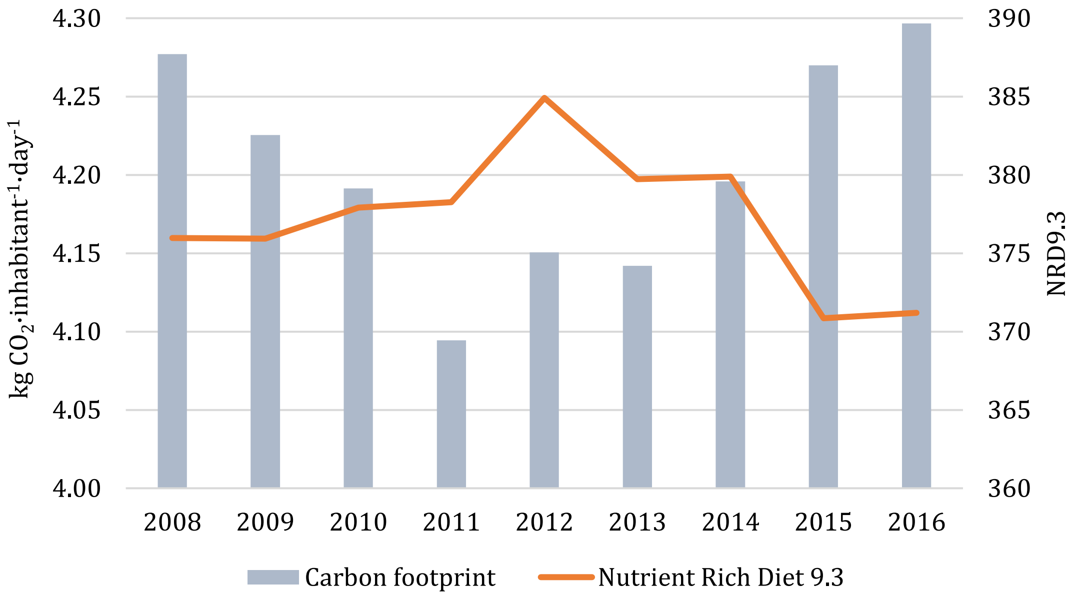

Figure 5.2. Carbon footprint values and Nutrient Rich Diet 9.3 scores for the different years included in the study period.

In the same way as reported by Hendrie et al. (2016), it can be suggested that higher energy intake leads to a higher CF. In addition, as expected, a slight decrease in the amount of food ingested lead to a reduction in emissions. However, this latter conclusion must be carefully evaluated, as CF varies considerably from one food product to another. When assessing in more detail the estimated results for the 2008-2016 period, the decrease in CF is associated with the progressive decline in the consumption of meat and dairy products until 2011, as it can be observed in Figure 5.3; although there is a general decrease in the consumption of all food groups, meat products are by far those that most influence the variation of the CF, followed by dairy products. Accordingly, although the consumption of dairy products decreases in the 2012-2016 period, the same trend is not observed in the consumption of meat, which progressively increases over the years. It consequently leads to an increase of the CF to its highest value in 2016. Otherwise, the increase in consumption of plant-based foodstuffs, such as fruits and vegetables, also contribute to increasing the CF, but these minimal variations are negligible (i.e., <0.05%).

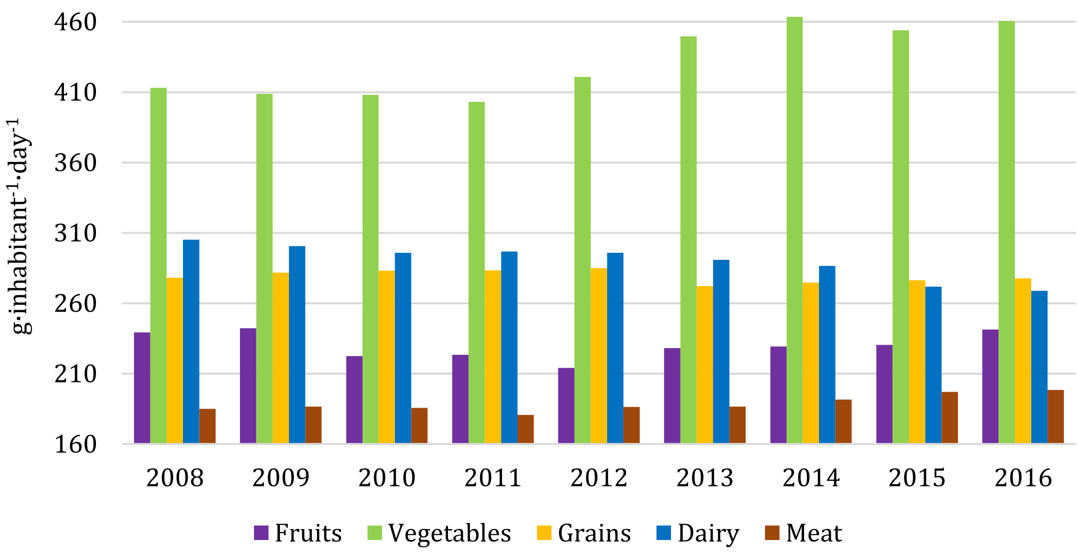

Figure 5.3. Consumption trend of the main food categories in the 2008-2016 period.

When comparing the CF with other studies available in the literature, it can be observed that the estimated value for the Portuguese diet is considerably high, being in line with diets rich in animal proteins (González-García et al., 2020). The rationale behind this high CF value is the large consumption of meat, which is nearly 200 g of meat·inhabitant^{-1}·day^{-1}. Therefore, in terms of meat consumption, the Portuguese diet could be assimilated to a high meat-eaters diet (>100 g of meat per day), according to Scarborough et al. (2014), which reported a CF of 7.19 kg CO_2 eq·inhabitant^{-1}·day^{-1} for high meat-eaters (Scarborough et al., 2014). The CF of the Portuguese diet is similar to those from other real dietary patterns such as 4.38 kg CO_2 eq inhabitant^{-1}·day^{-1} from the Spanish dietary pattern (Batlle-Bayer et al., 2019), or 4.11 kg CO_2 eq ·inhabitant^{-1}·day^{-1} from the French dietary pattern (Vieux et al., 2012), under the same system boundaries in all of them. It is important to note that all these diets mentioned above have a high caloric intake, as in the case of the Portuguese diet, so it would be advisable to reduce the energy intake to achieve a more sustainable consumption pattern.

As for the results obtained for the NRD9.3 score, it can be observed that the highest values of the index correspond to these years with the lowest CF figures, as shown in Figure 5.2. The years with a higher nutritional quality are those from 2012 to 2014, being the highest value (~385) in 2012. In contrast, the lowest nutritional values correspond to the years with the highest CF, reaching the lowest one (~371) in 2016. The main factor responsible for these variations is the ingested amount of saturated fats, sodium, and sugar as displayed in Table 5.1. A higher ingestion of these nutrients, whose consumption should be limited, leads to a remarkable decrease in nutritional quality, with the ingested amount of saturated fats and sugars higher than RDV (see Table 5.1). Keeping this in mind, dairy products, sweets and fats are the main food sources of these harmful nutrients (AECOSAN, 2021), so it would be advisable to reduce their consumption.

Table 5.1. Nutritional composition of the different years.

	Protein	Fiber	VitA	VitC	VitE	Ca	Fe	K	Mg	Sat. Fat	Na	Free sug.
Year	g	g	µg	mg	mg	mg	mg	mg	mg	g	mg	g
2008	113	25.8	1175	133	31.6	781	12.0	3328	278	39.3	833	118
2009	113	25.9	1162	133	31.6	775	12.0	3317	278	39.4	828	117
2010	113	25.5	1194	130	31.5	767	11.8	3254	273	39.4	823	115
2011	110	25.3	1172	129	30.8	757	11.5	3207	268	38.8	803	116
2012	110	25.0	1208	131	28.7	739	11.4	3218	260	37.3	771	115
2013	109	25.6	1297	139	29.5	741	11.4	3288	262	37.2	764	119
2014	111	26.0	1342	142	29.3	747	11.5	3325	263	37.1	778	119
2015	114	26.0	1316	141	29.7	752	11.8	3322	268	39.2	812	119
2016	114	26.5	1335	146	29.8	754	11.9	3368	272	38.9	812	120
RDV/ MDV*	50	25	800	100	9	1000	22	3500	310	20	1950	50

*RDV/MDV (Recommended/Maximum Daily Value)

According to the results, all the NRD9.3 values of the period studied are lower than those reported by González-García et al. (2018) for the diets traditionally coexisting in Portugal. In that study, NRD9.3 scores of 634, 637, 684 and 646 were reported for the Mediterranean, Atlantic, Vegan and Healthy diets, respectively. Consequently, a high level of deviation of the current consumption patterns with respect to the recommendations is detected as previously expected. However, it is important to note that the nutritional values quoted from González-García et al. (2018) are from recommended diets, and not from actual consumption patterns, as in this study. It is for this reason that quantities and proportions of real dietary patterns deviate from the recommendations, since non-recommended foodstuffs are consumed (e.g., processed foods) and it leads to a decrease in the nutritional quality. For instance, the NRD9.3 score reported for the Galician diet (242), is a much lower value than the one corresponding to the traditional recommendations from the Atlantic diet, (Esteve-Llorens et al., 2019b). Finally, considering the nutritional performance of the Portuguese diet, it is possible to quantify the level of deviation with respect to the traditional recommendations and to propose modifications to achieve a more sustainable diet.

Index-dependency nutritional quality

With the intention of validating the obtained results for the NRD9.3 index, they are compared with those obtained from a different nutritional quality index (i.e., Health Score) proposed by Van Dooren et al (2014). In this case, the cited index considers the ingestion of certain food categories, macronutrients and calorie intake (i.e., fruits, vegetables, total fatty acids, free sugar, fiber, sodium and kcal), and it also relates them with a reference value (Van Dooren et al., 2014). The obtained scores for this index are not completely in line with those of the NRD9.3 index as can be seen in Table 5.2. In this sense, the best results of the Health Score are for 2013 and 2014 (219 and 218 respectively) and the lowest scores correspond with 2008, 2009 and 2010 (208, 208 and 207 respectively). The rationale behind these results is mainly due to a higher consumption of vegetables, fiber, and a lower calorie intake in 2008, 2009 and 2010. These differences between nutritional indexes show that the selection of certain parameters for their calculation can have an important influence on the results and consequently, on the conclusions of a study (e.g., micronutrients, macronutrients, food categories and kcal); for instance, the energy intake, which is not considered in the NRD9.3, is a very influential factor in the Health Score index. Additionally, the selected reference values as well as the quality of the primary data on food consumption also influence the results which should be discussed and cautiously compared.

Table 5.2. Comparison of the Nutrient Rich Diet 9.3 index and Health Score results for the Portuguese diet.

	Nutrient Rich Diet 9.3	**Health Score**
2008	376	199
2009	376	200
2010	378	199
2011	378	201
2012	385	206
2013	380	210
2014	380	210
2015	371	204
2016	371	206
Average 2008 - 2016	377	204

5.3.2. PROPOSAL FOR AN ALTERNATIVE DIET

Based on these findings, an example of an alternative diet that would satisfy nutritional needs and have a reduced environmental impact, has been developed. The high caloric intake of the Portuguese dietary pattern leads to both a high CF and a low nutritional quality, as demonstrated above. Therefore, several modifications in the quantity and proportions of some food categories have been proposed to obtain an example of more sustainable diet, closer to the recommendations. Figure 5.4 shows the proposed modifications for the analysis, as well as the corresponding nutritional quality (NRD9.3 score) and CF.

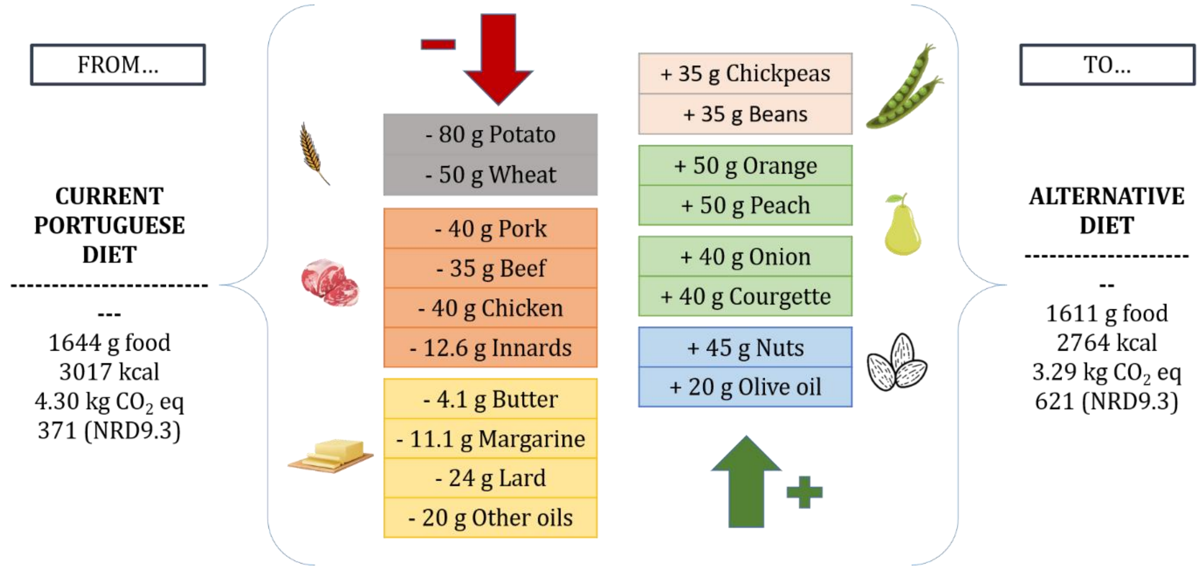

Figure 5.4. List of the modifications carried out in the Portuguese diet with the objective of achieve a more sustainable diet.

Regarding these specific modifications, 50 g of grains, 128 g of meat, 60 g of fats, 40 g of sugar and 80 g of potatoes have been removed. On the contrary, these removed quantities have been replaced by different alternative foodstuffs such as 70 g of legumes, 100 g of fruit, 80 g of non-starchy vegetables, 45 g of nuts and 20 g of olive oil (see Figure 5.4). Table 5.3 displays the consumed amounts of food categories in the Portuguese, Alternative and EAT-Lancet Commission diets. All these modifications lead to an increase of the nutritional quality of about 67%, with a resulting NRD9.3 score of 621, which is much higher than the original one (371) and is closer to the aforementioned values of the Atlantic (637) and Mediterranean (634) diets. The CF of the Portuguese diet is reduced by approximately 25%, with a final value of 3.29 kg CO_2 eq·inhabitant^{-1}·day^{-1}. This reduction in GHG emissions places the alternative diet at lower values than before and consequently, it is in line with the Mediterranean diet: 2.86 kg CO_2 eq·inhabitant^{-1}·day^{-1} (Castañé and Antón, 2017), 3.42 kg CO_2 eq·inhabitant^{-1}·day^{-1} (Van Dooren et al., 2014), 3.24 kg CO_2 eq·inhabitant^{-1}·day^{-1} (Van Dooren and Aiking, 2016); and the Atlantic diet: 3.01 kg CO_2 eq·inhabitant^{-1}·day^{-1} (Esteve-Llorens et al., 2019a). Finally, the daily energy intake decreases from the original 3017 kcal to 2764 kcal per capita; this reduction of around 250 kcal per day leads to a healthier diet, closer to the values recommended by EAT-Lancet Commission (Willett et al., 2018). Thus, although this value is still higher than the recommended energy intake (~2100 kcal·person^{-1}·day^{-1}), it is assumed to be an important first step towards gradual adherence to a more sustainable healthy dietary pattern.

Table 5.3. Consumed amounts of each food category in the Portuguese, Alternative and EAT-Lancet Planetary Healthy diet.

	Portuguese	Alternative	Eat-Lancet
		$g \cdot inhabitant^{-1} \cdot day^{-1}$	
Grains	335	228	232
Starchy vegetables	162	82	50
Vegetables	216	296	300
Fruits	241	341	300
Dairy	269	269	250
Meat	198	73	43
Eggs	23	23	13
Fish	55	55	28
Legumes	11	81	75
Nuts	7	52	50
Oils and fats	103	70	40

Considering these results, it is necessary to mention the importance of making a significant change in the current Portuguese diet, and to make an effort in the direction towards a better choice of foods that lead to a healthier and more environmentally friendly diet. Thus, it is necessary to adopt intervention strategies in different sections of society, such as family and community, school, and health system, through training and dissemination activities, nutritional recommendation campaigns, education of children at school, as well as through marketing and advertising campaigns promoting healthy food.

5.4. CONCLUSIONS

The environmental and nutritional quality of the Portuguese dietary pattern has been evaluated for the 2008-2016 period, considering the stages of production, transport, and household activities. On average for all the years of the period, a considerably high CF has been identified in comparison with those from recommended diets. However, it can be assimilated to real consumption patterns evaluated in other countries. Therefore, the remarkably high CF can be associated with the high consumption of energy and livestock products. In this sense, the CF value is much higher than those of the Mediterranean and Atlantic diets, which traditionally coexist in Portugal. When monitoring the CF throughout the 2008-2016 period, it has been detected that the CF remains practically unchanged over the years, with a slight decrease in the central years of the period, mainly related to a decrease in the consumption of meat, dairy, seafood, and fats. Variations in nutritional quality are significant, with the highest values in the central years and the lowest at the extremes. The rationale behind this is the lower consumption of harmful elements such as sodium, saturated fats, and sugars, which are more directly related with the ingestion of dairy products, fats, and sweets. Keeping in mind these results, the nutritional quality figures are considerably low and far from the values of the recommendations. Finally, considering the low nutritional quality and the high CF and caloric intake of the Portuguese diet, an example of a more sustainable diet has been designed, attending to the guidelines from Planetary Health Diet from EAT-Lancet Commission. Thereby, the quantities of certain foodstuffs (i.e., meat, grains, and fats) have been reduced, and replaced by others that are healthier and more environmentally friendly (i.e., fruits, vegetables, legumes, and nuts). As a result, the CF has been reduced and the nutritional quality has been increased very significantly, with values closer to those recommended.

In summary, measures should be taken to improve the nutritional quality and reduce both energy intake and CF, to achieve a healthier and more environmentally friendly lifestyle for the Portuguese population, through a variety of social campaigns, marketing, and education strategies. This research can serve as a reference for decision-makers, as well as to provide consumers with a clearer picture of what should be included in their food basket.

5.5. REFERENCES

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Appendix A: Portuguese food balance

Table 1: Daily food consumption grouped by categories and years.

		2008	2009	2010	2011	2012	2013	2014	2015	2016
		g·inhabitant^{-1}·day^{-1}								
Fruits	Orange	38.7	41.0	41.9	42.2	44.9	47.4	48.6	48.9	49.6
	Apple	53.6	53.8	46.8	47.5	51.9	55.0	54.7	57.7	57.0
	Peach	15.8	15.4	14.7	13.8	12.1	12.8	13.8	14.5	15.1
	Pear	18.4	18.6	17.3	18.6	10.0	14.9	15.4	9.5	9.4
	Banana	50.6	50.7	45.4	45.4	42.4	44.0	43.4	45.0	50.3
	Grape	11.6	11.9	11.0	10.5	10.3	10.0	10.0	10.0	9.5
	Strawberry	50.6	50.7	45.4	45.4	42.4	44.0	43.4	45.0	50.3
	Olive	2.8	2.6	2.3	2.1	0.9	0.7	0.9	0.9	1.2
Vegetables	Potato	156.2	153.8	147.4	146.6	150.6	157.8	160.8	161.4	161.8
	Tomato	26.4	27.6	27.0	26.4	27.8	27.6	28.2	28.8	29.0
	Cabbage	52.1	51.3	53.5	52.5	55.6	61.1	63.7	60.7	62.3
	Onion	52.1	51.3	53.5	52.5	55.6	61.1	63.7	60.7	62.3
	Carrot	52.1	51.3	53.5	52.5	55.6	61.1	63.7	60.7	62.3
Legumes	Chickpeas	2.5	2.5	2.5	2.2	2.5	2.6	2.6	2.6	2.6
	Beans	8.8	8.6	8.6	7.5	7.0	7.3	8.3	8.3	8.3
Grains	Rice	41.2	41.2	43.2	43.9	44.2	44.3	44.2	44.3	44.3
	Oats	5.0	5.0	5.0	4.7	4.6	5.0	5.0	5.0	5.0
	Wheat	203.1	206.9	205.1	204.2	204.2	190.8	192.4	193.6	194.9
	Rye	6.8	6.8	7.5	7.5	7.7	7.7	7.7	7.7	7.7
	Corn	22.1	21.8	22.2	23.2	24.3	24.3	25.5	25.7	25.7
Nuts		9.1	8.8	8.4	7.9	4.9	5.1	4.7	5.8	5.6
Dairy	Milk	210.6	200.7	197.7	197.7	194.9	189.2	185.4	167.8	167.5
	Yogurt	49.3	53.9	51.3	54.7	52.3	52.8	50.7	50.9	50.4
	Cheese	22.2	22.2	21.9	21.4	20.0	20.0	21.2	24.0	24.0
	Others	23.0	23.8	24.9	22.9	28.7	28.7	29.2	29.0	26.8
Eggs		21.4	21.4	22.3	20.1	20.1	20.6	20.3	23.9	23.1
Meat	Pork	64.9	66.1	63.4	61.7	60.1	59.9	61.1	62.1	59.0
	Lamb	5.2	5.2	5.0	5.0	4.0	4.0	4.0	4.0	4.0
	Beef	39.2	39.0	38.4	36.3	39.7	40.0	41.7	41.9	43.1
	Chicken	56.4	59.0	60.7	59.9	66.1	67.3	70.0	72.3	76.7
	Others	4.2	3.7	4.2	4.2	4.7	4.2	4.2	4.7	4.2
	Innards	15.0	13.8	14.0	13.6	11.9	11.1	10.6	12.1	11.3
Seafood	Cod	8.5	8.5	8.7	9.6	9.3	10.1	10.1	10.1	10.1
	Hake	41.7	41.7	40.6	37.7	34.8	33.2	30.1	33.0	34.0
	Mussel	14.6	14.6	13.8	11.2	10.1	8.7	9.0	10.1	10.9

Table 1: Daily food consumption grouped by categories and years (continued).

		2008	2009	2010	2011	2012	2013	2014	2015	2016
						g·inhabitant^{-1}·day^{-1}				
Sweets	Chocolate	9.3	9.1	9.3	9.3	9.1	9.6	9.6	9.6	10.0
	Sugar	67.0	66.6	66.6	67.2	66.8	67.9	68.4	68.9	68.9
	Honey	1.3	1.5	1.3	1.5	1.3	2.0	2.2	2.4	2.7
Oils/Fats	Olive oil	19.3	20.1	20.7	19.9	19.9	19.9	15.9	20.4	20.7
	Other oils (sunflower)	37.6	37.6	37.8	37.1	34.9	36.0	36.6	35.7	35.7
	Lard	30.4	30.4	30.4	30.4	28.2	26.9	27.1	28.7	28.4
	Butter	4.3	4.3	4.6	4.6	4.3	4.6	4.8	5.1	4.8
	Margarine	14.2	13.9	13.7	13.4	12.9	13.1	13.1	13.4	13.1
	Total	1639	1639	1614	1597	1594	1615	1626	1627	1644
						kcal·inhabitant^{-1}·day^{-1}				
	kcal	3045	3038	3007	3007	2952	2939	2932	3009	3018

SECTION III

SPANISH DIETARY HABITS

CHAPTER 6

Environmental and nutritional profile of food consumption patterns in the different climatic zones of Spain[10]

SUMMARY

One of the most effective ways to mitigate the effects of climate change at individual level is to change food consumption habits, given that the food system is one of the main human sources of greenhouse gases (GHG) emissions. In this sense, there is an urgent need to implement actions and to develop social awareness towards more sustainable diets that ensure nutritional quality and, at the same time, are environmentally friendly. Variation in consumption habits can be significant even within the same country, so recommendations aimed at improving consumption habits can also vary accordingly. Thus, the main goal of this study is to identify variations in food consumption patterns in terms of GHG emissions and nutritional intake adequacy for the 5 climatic zones of Spain. For this purpose, household food consumption data have been taken from surveys carried out by the Spanish Ministry of Agriculture, Fisheries and Food. It is foreseeable that the daily food basket and the eating habits associated with each territory will be justified not only on the basis of their geoclimatic conditions but also on the basis of culinary culture and tradition, socio-demographic profile and economic level. Variations in food consumption make it possible to relate northern areas to a higher carbon footprint (3.26 kg CO_2 eq·inhabitant^{-1}·day^{-1}) in comparison to those from southern regions (2.93 kg CO_2 eq·inhabitant^{-1}·day^{-1}), due to both higher consumption of animal origin products and higher energy intake. On the other hand, the higher consumption of fruits, seafood and legumes (17%, 34% and 11% respectively) in the northern regions than in southern ones also provides them a better nutritional profile. In view of the observed variations, the need to apply specific regional-addressed policies geared towards more sustainable consumption habits within the same country is highlighted.

[10] Esteve-Llorens, X[a]., Van Dooren, C.[b], Álvarez, M.[a], Moreira, M.T.[a], Feijoo, G.[a], González-García, S.[a], 2021. Environmental and nutritional profile of food consumption patterns in the different climatic zones of Spain. J. Clean. Prod. 279: 123580. ISSN: 0959-6526. https://doi.org/10.1016/j.jclepro.2020.123580.

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CHAPTER 6 - OUTLINE

6.1. INTRODUCTION

Given that one of the most effective way to combat climate change is through changing dietary habits (Batlle-Bayer et al., 2019; Vázquez-Rowe et al., 2017), there is an urgent need to incorporate changes towards a more sustainable diet. This perspective is fully in line with the Sustainable Development Goals, especially, the achievement of good health and well-being, adherence to responsible consumption and production systems and action for the climate (United Nations, 2018). This is why the number of studies on diets or dietary habits focusing on the assessment of environmental and health impacts has increased markedly (Corrado et al., 2019; González-García et al., 2018; Rohmer et al., 2018; Willett et al., 2018). In this sense, keeping the food system within environmental limits requires a combination of mitigation measures, including a healthy diet, technological and management improvements and the reduction of food losses (Springmann et al., 2018). In quantitative terms, a reduction of up to 50% of GHG emissions related to food consumption habits has been projected, in the case of dietary patterns with a predominance of plant foods (Willett et al., 2019).

Spain has been recently considered the healthiest country in the world mainly due to the Mediterranean diet and its health care system (Miller and Lu, 2019). In addition, the mortality rate associated with ischemic heart diseases is one of the lowest in Europe (Calvo-Malvar et al., 2016). In this sense, adherence to the Mediterranean diet implies a high consumption of vegetables, nuts, fruit, fish, whole grains and olive oil, foodstuffs that are clearly related to a low incidence of cardiovascular diseases among other chronic type (Martínez-González et al., 2019). The Atlantic Diet - assessed in depth in Section II - is another example of a healthy diet in the country, mainly associated with the population residing in the Northwest of Spain (Leis Trabazo et al., 2019; Rodríguez-Martín et al., 2019). However, there is also growing evidence that there is a shift from the above-mentioned dietary patterns (i.e., Mediterranean and Atlantic diets) to diets with higher fat, sugar and salt content diets (Batlle-Bayer et al., 2019; Blas et al., 2019). Increasing consumption of animal-based products and lower intake of plant-based foodstuffs directly affect quality of life, as evidenced by higher prevalence statistics in many chronic diseases, as well as reduced life expectancy (Afshin et al., 2017). In this regard, five of the top ten risk factors responsible for diseases such as high systolic blood pressure, high body mass index, high blood glucose and high total cholesterol are associated with unbalanced diets and poor nutritional profile (Global Panel on Agriculture and Food Systems for Nutrition, 2016). Consequently, a high intake of sodium and low intake of whole grains, fruits, vegetables and nuts (plant-based products) are the main causes of death related to food patterns (Afshin et al., 2017). It places the poor dietary habits in the first cause of death due to non-communicable chronic diseases Afshin et al., (2017). Therefore, the increase of excessive calories and animal-origin foodstuffs have been considered as the key factor in public health actions towards the promotion of healthier dietary patterns promoting the traditional consumption habits (Mertens et al., 2018).

While the globalization of the food sector imposes similar consumption patterns, it is also evident that eating habits and their quality are influenced by a large number of cultural, environmental, socio-economic and technological variables (Traill et al., 2014). In this sense, Spain is a country with a great diversity of cultures and lifestyles. Furthermore, despite being a relatively small country in extension (506,990 km^2), the variability of the climate is remarkable. Thus, arid, temperate, cold, polar and subtropical climates coexist in the country (AEMET, 2011). Bearing in mind these fluctuations, the main goal of this chapter is to identify variations in food consumption patterns in terms of GHG emissions and nutrients intake. Within this framework, the information supplied by the Ministry of Agriculture, Fisheries and Food by means of the Consumption, Marketing and Food Distribution Unit provides food consumption data from the Spanish shopping basket. Specifically, and according to the 5 main geographic areas, it is possible to consult the Household Database Program (MAPA, 2021) to identify daily per capita consumption and thus quantify the environmental impacts associated with food patterns and the nutritional profile of the average citizen of those target regions.

6.2. Materials and methods

6.2.1. Spanish climatic zones

Depending on the region of the country, the climate variation can be significant and can be classified on the basis of 5 climatic zones, considering additionally the delimitations established according to the Köppen climate classification system for the Iberian Peninsula (AEMET, 2011) For this purpose, different types of climate are defined using monthly average values of precipitation and temperatures with established ranges based mainly on their influence on the distribution of vegetation and human activity. The establishment of climate zones has been carried out by grouping the Spanish autonomous regions and it has been assumed that the food consumption data per capita for each zone correspond to the average value of the set of autonomous regions that constitute it.

Figure 6.1. Spanish autonomous regions grouped in five main different climatic zones

In order to synchronize the information on food consumption and the aforementioned Köppen classification, the Spanish regions have been grouped to have an approximation as accurate as possible to the climatic zones as displayed in Figure 6.1 and described below:

- Zone 1: Oceanic climate, located in the north of the country. This type of climate has mild temperatures throughout the year (~12.5ºC) with cool winters, and moderately hot summers Rainfall is abundant and widely distributed throughout the year The Autonomous Communities included are Galicia, Asturias, Cantabria, and the Basque Country.

- Zone 2: Continental climate, located just below the Zone 1, near to the central area of the country. It is characterized by extreme temperatures with cold winters and hot summers due to the absence of sea influence, with an average annual temperature around 15ºC. Rainfall is scarce and predominates in autumn and spring. It is made up of Aragón, Castile and León, La Rioja and the Chartered Community of Navarre.

- Zone 3: Mediterranean climate, located in the east and south-east of the country. Its temperatures are mild in winter and hot in summer with an average annual temperature of about 17.5ºC. Rainfalls are scarce and very irregular, and they become torrential in autumn, which can affect the viability of crops. Andalusia, Balearic Islands, Catalonia, Region of Murcia, Valencian Community are included in this zone.

- Zone 4: Continental climate with Mediterranean influence. In this zone winter is less cold than in the Continental climate but summer is hotter; the average annual temperature is about 17.5 ºC. Rainfall is scarce, but more abundant than in the continental climate. It is located in the center of the country, grouping the autonomous regions of Castile la Mancha, Extremadura and the Community of Madrid.

- Zone 5: Subtropical climate with warm and mild temperatures all year round with little difference between summer and winter (~21ºC). Although it does not have a high rainfall rate, the tropical climate provides humidity and short episodes of rain. It is located in the geographical area of the Canary Islands in latitude near the Northwest of Africa.

6.2.2. FOOD CONSUMPTION DATABASE

The household food consumption surveys carried out by the Ministry of Agriculture, Fisheries and Food (MAPA, 2021) are based on the daily purchase of food per inhabitant and collect information from around 12,000 Spanish households distributed by the different autonomous regions and with an average size of 2.69 people per household. Out-of-home food consumption was not considered in the surveys due to the scarcity of data related to specifications at the food level. Nevertheless, only 10% of the total food consumption is made out-of-home (MAPA, 2018). In this sense, household consumption habits are recorded daily and classified by product and food category with a barcode reader that provides information about the product and the purchased amount in the food basket. The information provided is finally collected in monthly series, which ensure the coverage of possible seasonal variations in the consumption of certain foodstuffs. However, it is important to bear in mind that the surveys do not provide an actual food intake per inhabitant since food waste should be expected to be produced at households, which should be subtracted from the food purchase values. In the present chapter, the food consumption data for the year 2017 have been collected, finally obtaining the average amount of food consumed per inhabitant and day throughout this period (i.e., g food·inhabitant^{-1}·day^{-1}). For the environmental and nutritional analysis of consumption habits, a total of 97 foodstuffs and beverages included in the food basket have been grouped into 14 food categories as detailed in Table 6.1 (i.e., fruits, vegetables, starch-based products, legumes, nuts, dairy products, eggs, meat, seafood, ready meals, sweets, oils, sauces and beverages). It includes the entire list of products in the database with the exception of non-liquid milks, coffee and infusions, broths and high alcoholic beverages, which represent less than 1% of the total amount of consumed food and, consequently, they do not influence the conclusions of the study. Otherwise, for the estimation of the nutritional adequacy, it is necessary to take into account the total food intake (that is, in and out of home consumption). For this reason, taking into account the lack of detailed information on the types of food consumed outside the home, household food consumption has been increased by 10%, which corresponds to the percentage of meals consumed away from home as mentioned above (MAPA, 2018). Additionally, in order to have a complete picture of food intake, the corresponding household food losses have been subtracted from the food basket according to Garcia-Herrero et al., (2018), since these quantities can become very significant for certain food categories (e.g., cereals - 25%; fruits, vegetables and legumes - 19%), so the final intake can vary markedly.

Table 6.1. Amount of food included in the daily food basket of the climatic zones identified for the assessment.

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Food category	g food· inhabitant^{-1}· day^{-1}				
Fruits	295.4	273.4	246.1	245.5	245.8
Vegetables	183.6	201.6	197.4	176.2	181.8
Starch-based products	252.8	219.8	225.9	202.9	215.5
Legumes	9.6	9.2	8.6	7.6	7.9
Nuts	13.8	15.0	15.2	11.7	13.1
Dairy	294.2	281.0	241.7	264.8	255.1
Eggs	26.8	25.3	22.7	21.2	20.6
Meat	119.3	118.0	109.6	108.9	86.4
Seafood	83.0	66.7	59.5	60.0	47.5
Ready meals	26.0	30.4	34.5	31.3	24.9
Sweets	25.4	21.3	20.5	17.8	23.8
Oils	41.6	33.6	30.8	27.1	32.6
Sauces	4.5	4.2	4.5	4.8	6.7
Beverages	172.8	160.6	233.9	215.4	240.7
Total	1549	1460	1451	1395	1402

6.2.3. GREENHOUSE GAS EMISSIONS DERIVED FROM FOOD CONSUMPTION

The estimation of GHG emissions from food consumption patterns, together with nutritional quality, in the defined climatic zones makes it possible to determine the degree of sustainability associated with consumption habits (FAO and WHO, 2019). Following the holistic approach of life cycle methodology (see section 2.2 from the Chapter 2) , the food production phase is by far the most important hotspot in the food chain in terms of GHG emissions and where the most important variations between regions may be found (Castañé and Antón, 2017). Therefore, the study is conducted through a "cradle to farm gate" perspective. Considering that the main objective of the study is to identify variations in individual food consumption habits in the different climatic zones of the country, other stages such as retailing, domestic activities, transport or final disposal of waste are dismissed assuming negligible differences between regions.

In line with Chapters 4 and 5, the average amount of food purchased per inhabitant and day has been selected as functional unit. The selection of non-escalated energy functional unit allows the results to be compared with other consumption patterns, adjusted or not to the energy intake; in any case, the ultimate function of the system is to meet the daily food requirements. Regarding the data acquisition for carbon footprint (CF) estimation, the life cycle inventory collects detailed information on the production and processing phase of 97 foodstuffs from 30 LCA studies (see Table 1 in the Appendix). When possible, values from Spanish production systems have been selected. Otherwise, figures from similar production systems or global average values, such as the reported by Clune et al., (2017), have been incorporated. In some cases, some foods include transportation to the distribution center (Berners-Lee et al., 2012; Clune et al., 2017). However, the contribution of this stage to the total CF can be considered negligible. Additionally, in some foodstuffs, certain food commodities have been assimilated to others. That is the case of nectarine to peach, hazelnut to almond and milkshake to milk, on the basis of similarity in nutritional value, botanical family and/or agricultural method

6.2.4. NUTRITIONAL ADEQUACY OF DIETS

In order to estimate the variations in terms of nutritional quality between the delimited climatic zones, the suitability of the intake of the most important micro and macronutrients has been examined. To this end, the Nutrient Rich index has been proposed for analysis (Van Kernebeek et al., 2014), which is a variation of the Nutrient Rich Food index defined by Drewnowski, (2009). This score is based on a set of nutrients whose consumption should be increased and others that should be limited and a detailed description of it can be found in section 2.3.1. from the Chapter 2. Thus, the intake of qualifying and disqualifying nutrients has been quantified by climatic zone, relating them to recommended daily values (RDVs) and maximum recommended values (MRV) for an adult woman, taken from Codex Alimentarius (FAO/WHO, 2017). The required nutritional information on the content of micro and macronutrients for the 97 foodstuffs included in the study has been extracted directly from the Spanish Food Composition Database (AECOSAN, 2021).

6.2.5. SUSTAINABLE NUTRIENT RICH DIET 3.3

According to FAO and WHO (2019), the sustainability assessment of the food consumption patterns in the present chapter combines their environmental and nutritional quality. In this sense, a novel index proposed by Van Dooren et al., (2017), which reflects both climate and nutritional impact of foods in a single value, is taken as reference. This methodology is a variant of the previously designed Nutrient Rich Food 9.3 (NRF 9.3) index (Drewnowski, 2009), and takes into account the strong correlations that exist between GHG emissions from foodstuffs and their content in certain macronutrients. The complete description of this methodology is displayed in section 2.3.4. from the Chapter 2. In this case, the reference intakes for the recommended daily RDV) and maximum daily (MRV) values (see Table 2 of the Appendix) are taken also from Codex Alimentarius (FAO/WHO, 2017) and the European Food Safety Authority (EFSA, 2019).

6.3. RESULTS AND DISCUSSION

6.3.1. GREENHOUSE GAS EMISSIONS DERIVED FROM FOOD CONSUMPTION HABITS

The resulting CF for the different delimited zones (see Figure 6.1) according to the specific amount of food consumed in each of them, varies between 2.93 kg CO_2 eq·inhabitant^{-1}·day^{-1} in Zone 4 and Zone 5 and 3.26 kg CO_2 eq·inhabitant^{-1}·day^{-1} in Zone 1. The results for Zone 3 are slightly higher than those for Zones 4 and 5 with 2.94 kg CO_2 eq·inhabitant^{-1}·day^{-1}. Regarding the CF in Zone 2 is 3.05 kg CO_2 eq·inhabitant^{-1}·day^{-1} (see Table 6.2). In this way, it can be observed that Zone 1 distances itself from the remaining territories, with a difference of about 0.32 kg CO_2 eq·inhabitant^{-1}·day^{-1} with respect to the area with the lowest CF. With a minor difference, Zone 2 has a CF of 0.12 kg CO_2 eq·inhabitant^{-1}·day^{-1} higher than the lowest figure (Zone 4). On the other hand, Zone 3, Zone 4 and Zone 5 are those with the lowest CF. At the same time, it also can be observed in Table 6.2 that a higher energy supply is related to a higher CF. One of the limitations of the present study is that individual data on food consumption is not available to carry out a statistical test and to determine the level of significance of the variations; for this reason, the results are expressed in an observational rather than causal manner.

Table 6.2. Daily carbon footprints (CF) and energy supply per person for each climatic zone and national average.

	CF	**Energy supply**
	kg CO_2 eq·person^{-1}·day^{-1}	kcal·person^{-1}·day^{-1}
Zone 1	3.26	1983
Zone 2	3.05	1791
Zone 3	2.94	1785
Zone 4	2.93	1653
Zone 5	2.93	1788
National average	3.02	1800

Regarding the relationship between GHG emissions derived from diet and climatology, Zone 1 is associated with oceanic climate and includes the autonomous regions with the lowest average annual temperatures (except for specific alpine climate points, distributed throughout the Iberian Peninsula and associated with mountain ranges, which are out of the scope of this study), just below is Zone 2 (See Figure 6.1) where the continental climate prevails and has a slightly higher annual average temperature (~+2.5ºC). In the remaining areas (i.e., Zone 3, Zone 4 and Zone 5), the average annual temperature is about 5ºC higher than in Zone 1. In these areas the Mediterranean climate predominates, although differences linked to the continental climatic influence in the interior (Zone 4) as well as to the subtropical climate in the islands (Zone 5). In colder climates such as those from the Netherlands, also higher values have been reported with 4.3 kg CO_2 eq·inhabitant^{-1}·day^{-1} (Van de Kamp et al., 2017) including in this case the consumption stage. Taking into account the results obtained, it can be stated as a first approximation that climates with colder average annual temperatures are associated with a higher CF than those with warmer temperatures throughout the year. However, there is little evidence so this statement should be taken with caution.

Taking into account the available information on CF associated with current consumption patterns in Spain (Batlle-Bayer et al., 2019; Sáez-Almendros et al., 2013), the mean value of this chapter is significantly lower (3.02 kg CO_2 eq·inhabitant^{-1}·day^{-1}) compared to published values. In this sense, Batlle-Bayer et al., (2019) reported 3.68 kg CO_2 eq·inhabitant^{-1}·day^{-1} for the foodstuffs production stage. This difference may be associated differences in the CF values of the foodstuffs as well as with the inclusion of bottled water, that is not included within the scope of this study. Otherwise, Sáez-Almendros et al. (2013) reported higher values: 4.39 kg CO_2 eq·inhabitant^{-1}·day^{-1} by including the retailing stage and considered the FAO food balance sheet as source of consumption data, but in this case without considering food losses. Additionally, the results from Zone 1 can be comparable with those reported in Chapter 4: 4.80 kg CO_2 eq·inhabitant^{-1}·day^{-1}, associated to the current food consumption patterns in the Autonomous Community of Galicia (Northwest Spain). It is also a higher value than the obtained for the present study, and the rationale behind this is the existing variation in terms of the selected inventory database; accordingly, the current food consumption patterns from Galicia were directly extracted from food consumption surveys, and consequently, the consumption data and their corresponding impacts are remarkably different.

In order to detect the variations between GHG emissions and foodstuffs consumption in each zone, Figure 6.2 displays in a combined manner the percentage of grams consumption of each food category, as well as its corresponding contribution to the total CF. Bearing in mind the results, the consumption ratio of the food categories varies by area, which could extend to the climatic variation between zones and it is consequently associated with variations in the CF as well as in the contributions of food categories to GHG emissions.

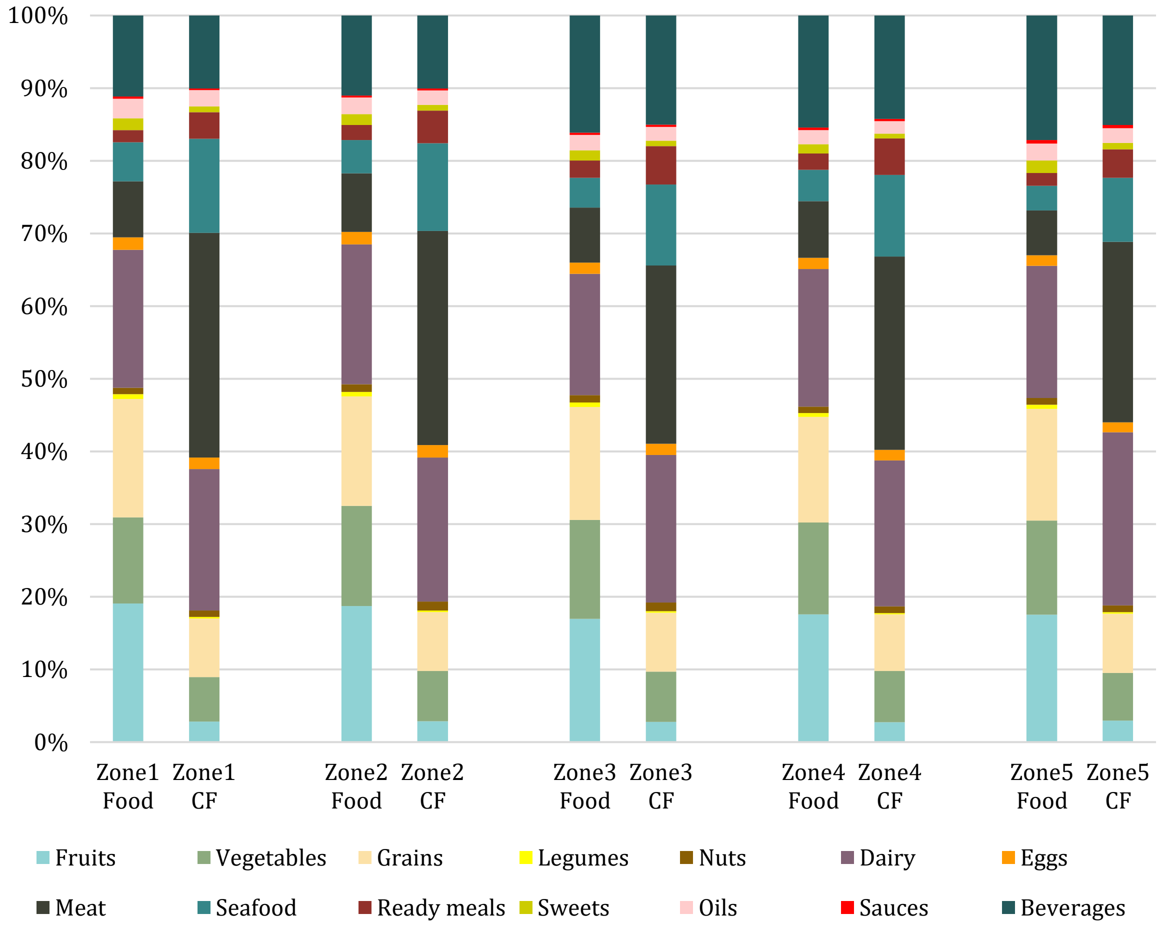

Figure 6.2. Contribution (in %) of the consumption of each food category to the total amount consumed (Food), as well as the corresponding contribution to the total carbon footprint (CF).

In terms of average values, the food categories that are consumed the most (~45% of total consumed food at households and ~35% of the calorie contribution) that form the basis of the consumption pattern are those that contribute the least to the CF (~17% of total contributions). This is the case of fruits, vegetables and starch-based foodstuffs. In contrast, animal-based foodstuffs, such as meat and dairy products, which account for about 25% of total food consumption and about 23% of the caloric contribution, represent around 50% of the GHG emissions on average in all areas. Table 6.3 displays the contributions (in %) of the different food categories to the CF in each climatic zone. However, there are some variations in the consumption of animal-based foodstuffs such as meat, dairy and eggs, depending on the climatic zone, these food groups are mainly responsible for the fluctuations of the corresponding CFs. In this sense, Zone 1 is the largest consumer of livestock products (including meat, dairy and eggs) with 449.4 g·inhabitant^{-1}·day^{-1} Otherwise, the areas with the lowest CFs (i.e., Zone 3, Zone 4 and Zone 5) have an intake of around 65 g lower than the former (on average). Regarding these fluctuations, it is important to highlight the major influence of the beef meat, whose consumption is approximately 80% higher in Zone 1 than in Zone 3, Zone 4 and Zone 5 on average. Therefore, beef consumption becomes one of the main causes of the variation of total CF among climatic zones due to its relevance (i.e., 28.6 kg CO_2 eq·kg^{-1}) (Clune et al., 2017). In this way, the northern region of Spain is characterized by intense rainfall throughout the year, which allows the extension of large grazing areas; consequently, the availability of beef meat for consumption is very high, since it is the main livestock area of the country (MAPAMA, 2016). This is the reason why a reduction on the ingestion of livestock products should be advisable in these areas, taking into account their huge environmental impact. In this context, it would be interesting to develop new policies aimed at reducing the consumption of livestock products and at the same time promoting those produced in a more sustainable way. This could constitute a large difference in terms of environmental impact, since for instance, there is a great variation between the CF of conventional beef (28.6 kg CO_2 eq·kg^{-1}) (Clune et al., 2017) and the organic one (10.4 kg CO_2 eq·kg^{-1}) (Desjardins et al., 2012).

Table 6.3. Contributions (%) of the different food categories to the carbon footprint in each climatic zone

Food category	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
			%		
Fruits	2.84	2.88	2.78	2.72	2.98
Vegetables	6.12	6.92	6.91	7.07	6.55
Starch-based products	8.03	8.08	8.12	7.79	8.17
Legumes	0.22	0.22	0.22	0.20	0.20
Nuts	0.89	1.22	1.19	0.90	0.90
Dairy	19.49	19.85	20.31	20.10	23.84
Eggs	1.59	1.68	1.53	1.46	1.39
Meat	30.91	29.49	24.55	26.59	24.85
Seafood	12.95	12.07	11.14	11.24	8.78
Ready meals	3.64	4.50	5.29	5.02	3.95
Sweets	0.80	0.76	0.73	0.65	0.87
Oils	2.23	2.01	1.89	1.71	2.04
Sauces	0.26	0.27	0.29	0.31	0.42
Beverages	10.03	10.04	15.04	14.24	15.08

With respect to the food categories that contribute to a lesser extent, seafood is consumed more in Zone 1 than in the remaining areas at an average of 25 g·inhabitant^{-1}·day^{-1}, which may be related to the high availability of fishery products from the Cantabrian-Northwest fishing grounds, the most important in the country (CEPESCA, 2017). Likewise, the abundant consumption of seafood is also related with the so-called Atlantic diet, traditionally located in the northwest part of the country (Leis Trabazo et al., 2019) as described in Chapter 3. Beverages are consumed more in Zone 3, Zone 4 and Zone 5 than in Zone 1 and Zone 2. In this sense, the warmest territories consume on average 63 g·inhabitant^{-1}·day^{-1} more than the coldest ones, which can be translated into about 37 kg CO_2 eq inhabitant^{-1}·year^{-1}. The beverages category includes purchased beverages such as wine, beer, juice and soft drinks, excluding bottled mineral water. As for fruits, although the quantities consumed in Zone 1 and Zone 2 are approximately 17% and 11% higher respectively than in the rest of the zones, the difference between the derived GHG emission is not large enough to be considered relevant (2.5 kg CO_2 eq inhabitant^{-1}·year^{-1} on average) due to the low CF of these foodstuffs. The other food categories (i.e., legumes, nuts, ready foods, sweets, oils, and sauces) have a similar contribution to the environmental profile in terms of GHG emission in all the zones assessed, since the average quantities consumed are similar in all of them (see Table 6.1).

In relation to these results, it can be demonstrated that the delimited areas meet with the different climatic zones, and their different consumption habits are associated with different environmental impacts. In this sense, when adjusting the energy intake of all climatic zones to 2000 kcal, results are not the same, since as it can be seen in Table 3 of the Appendix, the consumed amounts of each food category vary accordingly. The greater consumption of livestock products should take place in Zone 2 and Zone 4 (~455 g ·inhabitant^{-1}·day^{-1}), followed by Zone 1 (~425 g ·inhabitant^{-1}·day^{-1}), and Zone 3 and Zone 5 (~390 g ·inhabitant^{-1}·day^{-1}) respectively. Consequently, the lowest CF remains in Zone 5 (2.91 kg CO_2 eq·inhabitant^{-1}·day^{-1}), but otherwise Zone 4 is the one with the highest figure (3.20 kg CO_2 eq·inhabitant^{-1}·day^{-1}) due to the largest contribution of animal-origin foodstuffs.

6.3.2. NUTRITIONAL ADEQUACY OF THE CLIMATIC ZONES

The determination of nutritional quality has been made based on the correlation of the consumption of certain micro- and macronutrients with the daily intake recommendations (RDV/MRV) for them (EFSA, 2019; FAO/WHO, 2017) as previously mentioned. In this sense, the results are obtained as the percentage of nutrient intake in relation to the RDV/MRV according to Equation 2.1 from Chapter 2. Figure 6.3 displays the $NR_{nutrient}$ scores for all the considered nutrients in the different climatic zones identified for assessment. According to the results, for certain qualifying nutrients, such as protein, vitamin C and vitamin E, daily needs are covered throughout the country. In this way, high protein consumption is related with the high intake of meat in all the regions, and especially in Zone 1. The optimal intake of vitamin C is mainly due to the consumption of fruits (more specifically citrus, which are the most consumed fruits in the country) and milk, which are foods rich in this element. Finally, the current consumption of nuts and oils (sunflower and olive) guarantees an optimal daily intake of vitamin E.

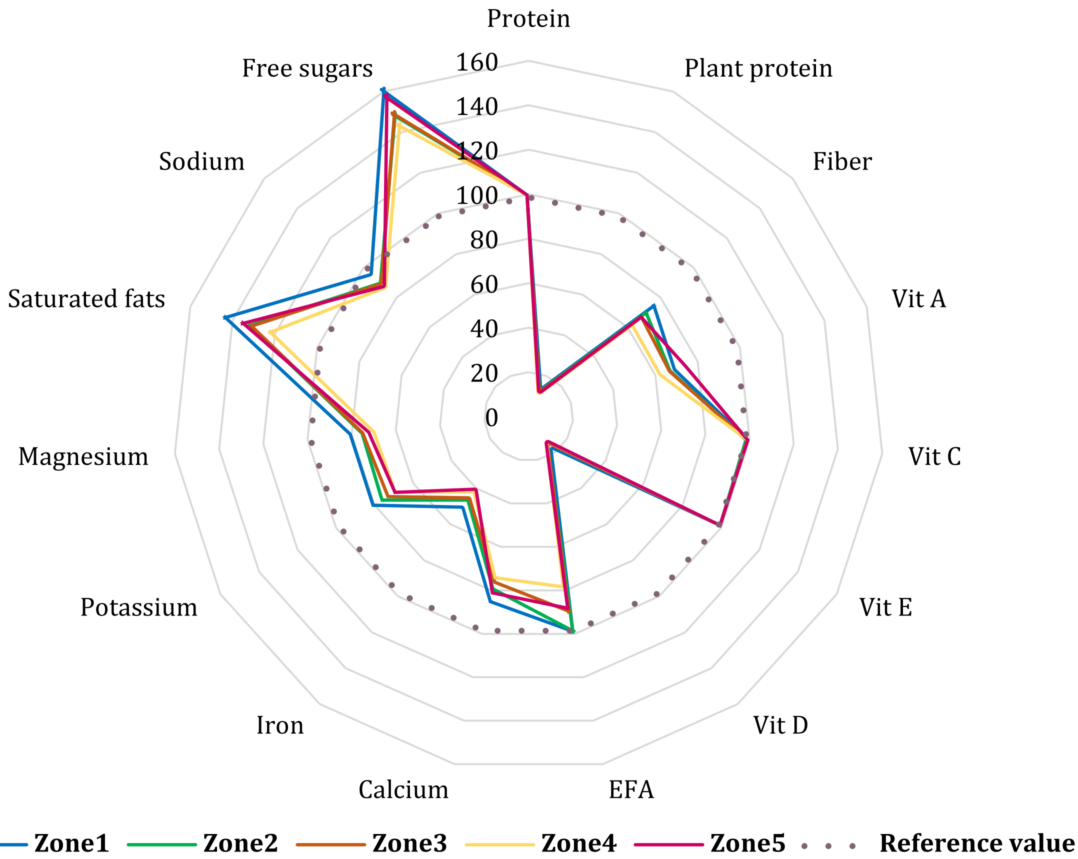

Figure 6.3. Nutrient Rich scores for all the considered nutrients in the climatic zones

Contrarily to the three qualifying nutritional elements previously mentioned, the others obtain a $NR_{nutrient}$ score under the RDV depending on the nutrient and the zone to a greater or lesser extent. Thus, in terms of plant-based protein, the consumption of this nutrient is much lower than that of the RDV (around 85%) throughout the country. It is a considerably low value taking into account that it is advisable to increase the consumption of plant-based protein and decrease that of animal origin (de Gavelle et al., 2017; Jayathilake et al., 2018). Therefore, it is advisable to reduce the amount of protein of animal origin, compensating it with more advisable vegetable-based protein sources such as legumes (Margier et al., 2018).

Fiber intake is close to the recommendations, especially in Zone 1 and Zone 2 where its consumption is around 10% and 5% higher than Zones 3, 4 and 5. It is directly related to higher consumption of fruits, which is about 17% and 11% higher, respectively. Nevertheless, intake of fiber should increase between 25% and 35% depending on the zone to reach the RDV with higher consumption of vegetables, fruits and whole grains, which would have a negligible impact on the increase in GHG emissions due to the low CF of these foods. Similarly, vitamin A intake should increase by about 30%. In relation to the vitamin D score, it can be concluded that there is a significant lack of intake, since, according to its content in the daily amount of consumed food, only about 16% of RDV is provided throughout the country. However, it is important to consider that vitamin D from sunlight exposure is not taken into account, and these means of supply could be relevant. In this way, in order to reduce the risk of chronic diseases resulting from this vitamin deficiency, such as cardiovascular diseases bone metabolic disorders and diabetes (Wang et al., 2017), their consumption should be significantly increased through increased consumption of foodstuffs rich in this element, such dairy or seafood and thus reducing the ingestion of meat products. Furthermore, an increase in the sunlight exposure should also be taken into account as source of vitamin D.

The intake of EFA is adequate for Zone 1 and Zone 2, reaching the $NR_{nutrient}$ score of 100%; the relationship between high seafood consumption, the Atlantic diet and the northern territory of the country can be related to adequate EFA consumption. That is not the case for the remaining zones, where the daily ingestion is close to the recommendations, but needs to be improved. In this sense, a higher consumption of seafood is what makes the difference between Zone 1 and the rest of the territory, so the northern example should be followed by that of at least equal consumption of seafood and a lower ingestion of meat. Calcium, potassium and magnesium scores are around 80% of the RDV on average; these percentages are higher in Zone 1 where scores reach 87%, which is related to increased consumption of seafood, dairy products, potatoes and legumes. Finally, iron intake is about half the RDV in all regions, whose deficiency can lead to anemia (Cavalcanti et al., 2014), so a greater intake of iron-rich products such as legumes is recommended.

For disqualifying nutrients (i.e., saturated fats, sodium and total sugars), it can be observed that $NR_{nutrient}$ scores are at the edge of MRV for sodium and are much higher for saturated fats and total sugars (~135 and 160% of MRV on average). In this sense, a higher consumption of dairy products, precooked and processed foods and sweets in the Zone 1 leads to a slightly higher score for these disqualifying nutrients. Leaving aside the ultra-processed meat and food as well as reducing the intake of sweets as much as possible and instead consuming more fruits and olive oil would be advisable to reduce the excessive dose of the mentioned disqualifying macronutrients. It would also be beneficial in terms of environmental impact since the lower CF of these more beneficial foodstuffs would lead to a decrease in GHG emissions. As for sodium, although the intake is slightly lower than the MRV, it is important to note that salt is not included among the 97 foodstuffs of the study, so it can be expected that the daily intake of sodium is much higher, far exceeding the recommended dose. In this sense, considering that a high intake of sodium is the main cause of death related to poor food patterns (Afshin et al., 2017), it should be in the spotlight of policies aimed at promoting healthier dietary habits. To sum up, it can be said that in terms of nutritional adequacy, there is a variation in the scores between the different delimited areas. This supports the proposed hypothesis about possible fluctuations of the food consumption habits according to the climatic conditions and lifestyle of each inhabitant, and more importantly, that policies aimed at improving the nutritional adequacy may be different between regions even within the same country.

6.3.3. Sustainability scores for the different climatic zones

Through the correlation that exists between nutrients and their corresponding GHG emissions, sustainable scores are obtained through the Sustainable Nutrient Rich Diet (SNRD) index (See Equation 2.4 from the Chapter 2). Figure 6.4 presents the sustainability scores for the five delimited zones, in relation to their corresponding CF. As mentioned in section 2.3.4 from the Chapter 2, a higher SNRD is linked with a more sustainable diet and vice versa. This is an indicator of the high content of animal-origin and convenience food products in the food consumption patterns, as there is a strong positive correlation between products of animal origin and GHG. Thus, the higher the plant food content and the lower the content of livestock and precooked food, the higher the SNRD figure and vice versa.

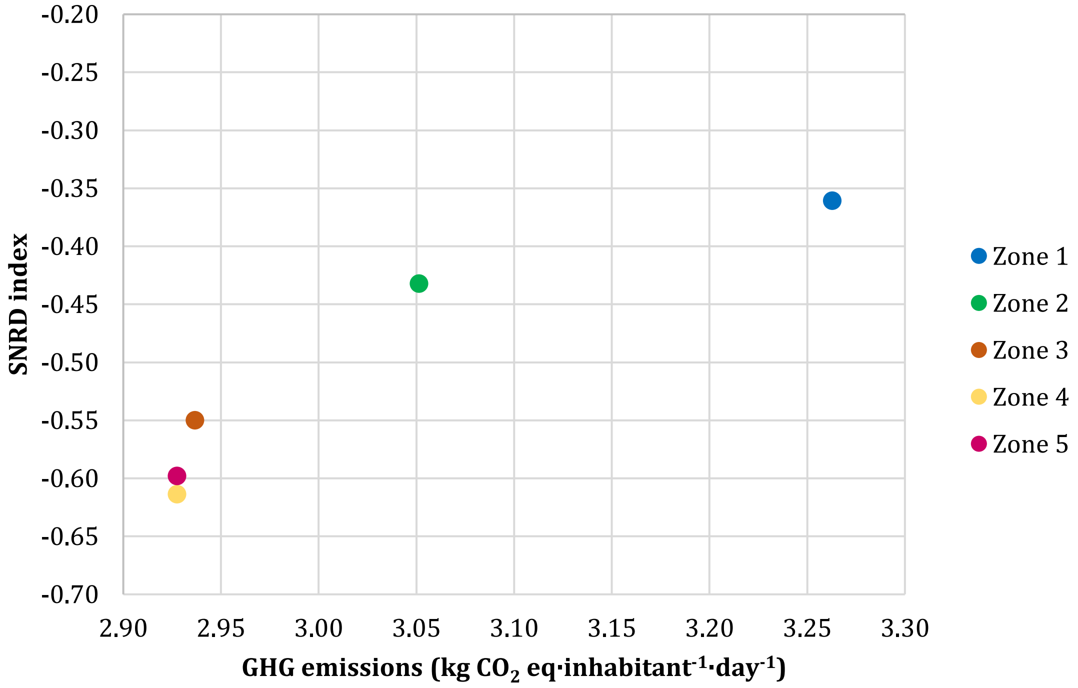

Figure 6.4. SNRD index scores for the climatic zones proposed for analysis in relation with their respective CF.

In this case, Zone 1 obtains the highest SNRD value (-0.36) against expectations, (as higher GHG emissions should lead to lower SNRD) followed by Zone 2 (-0.43), Zone 3 (-0.55), Zone 5 (-0.60) and Zone 4 (-0.61) respectively. However, the rationale behind this is that, although Zone 1 had the highest CF score, the difference with the other regions is not important enough to be a determining factor of sustainability. In this sense, its better nutritional adequacy makes the difference for greater sustainability. As mentioned in the previous section, the northern region is characterized by a higher intake of vegetables, seafood, dairy, potatoes and legumes. Zone 2 ranks second in terms of sustainability, mainly due to lower nutritional adequacy, but with very close value to Zone 1. Finally, the remaining areas obtain a similar sustainability figure, also derived from practically the same CF and nutritional adequacy. As for the relationship between climatic conditions and sustainability of the consumption habits, it has been determined that, for the present case study, colder climates obtain a better SNRD score, especially due to a higher consumption of nutrients with a strong correlation with low GHG emissions such as plant-based proteins, fiber and EFA. It has to be noticed that one of the main limitations of these results is that as far as we know, it is the first time that SNRD index is applied to dietary habits and consequently, they cannot be compared with other consumption patterns. Therefore, further research should be focused on extending the available literature for this SNRD index.

6.4. CONCLUSIONS

This chapter evaluated the variations in food consumption patterns in Spain from a sustainability point of view, considering consumption data from household food surveys, the related GHG emissions and the corresponding nutritional adequacy. To this end, the country has been classified into five different zones according to the climatic conditions (Oceanic, Continental, Mediterranean, Continental with Mediterranean influences and Subtropical). Based on the results, both GHG and nutritional adequacy differ across the zones. In this sense, the coldest regions located in the north of the country are related to the increase in CFs mainly due to a higher consumption of livestock products and a higher energy intake. In terms of nutritional adequacy, the northern zones obtain the best scores derived from a more balanced diet that includes a higher consumption of fruits, vegetables, seafood and olive oil compared to the rest of the areas. Regarding the livestock products, which are those with the highest environmental impacts (specifically red meat), it should be interesting to develop new policies aimed at reducing their consumption and at the same time promoting moderate consumption of those produced under a more sustainable way. Likewise, the inclusion of other indicators such as land use or water use, would be interesting to complement the results from this study.

Variations in food consumption patterns and their corresponding sustainability (i.e., in terms of GHG emissions and nutritional quality) according to the different climatic zones detected in this research can serve as a first step to study the relationship between dietary habits and the environmental conditions of the territory. Furthermore, given the urgent need to achieve more sustainable consumption patterns as an effective measure for the climate change mitigation, specific regional policies, such as nutrition and environmental education, should be needed to improve food choices in supermarkets, including within the same country as in the present case study.

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APPENDIX

Table 1. Carbon footprint values for the 97 products included in the food basket

Food category	Food product	kg $CO_2 \cdot kg^{-1}$	Reference
Fruits	Orange	0.15	(Aguilera et al., 2015a)
	Mandarin	0.15	
	Lemon	0.15	
	Banana	0.3	
	Apple	0.12	
	Pear	0.12	
	Peach	0.12	
	Nectarine	0.12	
	Apricot	0.12	
	Strawberry	0.65	(Clune et al., 2017)
	Melon	0.24	(Aguilera et al., 2015a)
	Watermelon	0.24	
	Green plum	0.12	
	Cherry	0.48	(Clune et al., 2017)
	White grape	0.12	(Aguilera et al., 2015a)
	Kiwi	0.33	(Clune et al., 2017)
	Avocado	0.3	(Aguilera et al., 2015a)
	Pineapple	0.72	(Clune et al., 2017)
Vegetables	Tomato	0.26	(Aguilera et al., 2015b)
	Onion	0.22	
	Garlic	0.24	
	Cabbage	0.24	
	Cucumber	0.33	(Clune et al., 2017)
	Green beans	0.3	(Aguilera et al., 2015b)
	Green pepper	0.23	
	Mushrooms	0.27	(Clune et al., 2017)
	Lettuce	0.24	(Aguilera et al., 2015b)
	Asparagus	0.24	
	Spinach	0.54	(Clune et al., 2017)
	Eggplant	1.35	
	Carrot	0.22	
	Zucchini	0.42	
	4th range salad	0.97	

Table 1. (Continued)

Food category	Food product	kg $CO_2 \cdot kg^{-1}$	Reference
Starch-based foods	Potato	0.24	(Aguilera et al., 2015b)
	White bread	0.67	(Notarnicola et al., 2017)
	Rice	1.66	(Aguilera et al., 2015b)
	Pasta	0.45	(Röös et al., 2011)
	Pastries	2.5	(Werner et al., 2014)
	Wholemeal biscuits	1.3	(Berners-Lee et al., 2012)
	Wholemeal cereals	1	
Legumes	Chickpeas	0.67	(Clune et al., 2017)
	Beans	0.23	(Aguilera et al., 2015b)
	Lentils	1.03	(Clune et al., 2017)
Nuts	Olives	0.56	(Clune et al., 2017)
	Almonds	0.23	(Volpe et al., 2015)
	Peanuts	0.62	
	Walnuts	0.53	
	Hazelnuts	0.23	
	Pistachios	0.53	
Dairy	Milk	1.23	(Ballús et al., 2014)
	Milkshake	1.23	
	Yogurt	1.5	(González-García et al., 2013a)
	Butter	7.3	(Vergé et al., 2013)
	Cheese	10.14	(González-García et al., 2013b)
	Ice-cream	2.8	(Werner et al., 2014)
	Custard	1.5	(Berners-Lee et al., 2012)
	Eggs	1.8	(Nielsen et al., 2013)
Meat	Beef	28.6	(Clune et al., 2017)
	Chicken	2.5	(González-García et al., 2014)
	Lamb	10.85	(Jones et al., 2014)
	Pork	4.96	(Noya et al., 2017)
	Sausage	3.42	(Noya et al., 2016)

Table 1. (Continued)

Food category	Food product	kg $CO_2 \cdot kg^{-1}$	Reference
Seafood	Hake	14.55	(Iribarren et al., 2011)
	Sardine	0.36	(Almeida et al., 2015)
	Tuna	1.6	(Hospido et al., 2006)
	Trout	2.75	(Aubin et al., 2009)
	Sole	2.26	(Iribarren et al., 2011)
	Cod	2.16	(Ziegler et al., 2003)
	Mackerel	0.61	(Iribarren et al., 2011)
	Salmon	3.76	(Clune et al., 2017)
	Sea bass	3.55	
	Gilt-head bream	2.26	(Iribarren et al., 2011)
	Turbot	14.51	(Clune et al., 2017)
	Monkfish	9.38	(Iribarren et al., 2011)
	Clam	1.59	(Iribarren et al., 2010)
	Mussel	1.59	
	Squid	3.86	(Iribarren et al., 2011)
	Prawn	14.85	(Clune et al., 2017)
Canned food	Vegetables	3.7	(Berners-Lee et al., 2012)
	Fruit	1.05	
	Fish	4.15	
Ready meals	Preserved	8.15	(Berners-Lee et al., 2012)
	Frozen	4.15	
	Soups/creams	2.9	
	Pizza	4.15	
Sweets	Chocolate	1.00	(Werner et al., 2014)
	Honey	1.00	(Scarborough et al., 2014)
	Sugar	0.24	(Klenk et al., 2012)
Oils/Fats	Olive oil	1.47	(Pattara et al., 2016)
	Sunflower oil	0.76	(Muñoz et al., 2014)
	Margarine	1.66	(Nilsson et al., 2010)
Sauces	Ketchup	1.6	(Berners-Lee et al., 2012)
	Mayonnaise	1.95	(Hetherington et al., 2012)
Beverages	Wine	0.75	(Berners-Lee et al., 2012)
	Beer	0.45	
	Juice	0.67	(Jungbluth, 2013)
	Soft drinks	0.85	(Berners-Lee et al., 2012)

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Table 2. Recommended/Maximum daily values for each nutrient considered

Micro/macro nutrient	units	Recommended/Maximum Daily Value
Protein	g	50
Plant protein	g	50
Fiber	g	25
Vitamin A	µg	800
Vitamin C	mg	100
Vitamin E	mg	9
Vitamin D	µg	15
Essential Fatty Acids	g	12
Calcium	mg	1,000
Iron	mg	22
Potassium	mg	3,500
Magnesium	mg	310
Saturated fats	g	20
Sodium	mg	1,950
Total sugars	g	50

Table 3. Food consumption adjusted to 2000 kcal and corresponding carbon footprint for the different climatic zones

Food category	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
	g·inhabitant^{-1}·day^{-1}				
Fruits	269.32	275.85	249.21	268.51	249.07
Vegetables	172.74	208.80	205.19	199.40	188.86
Starch-based products	220.44	211.67	218.99	211.84	208.58
Legumes	8.78	9.30	8.70	8.32	8.00
Nuts	13.14	15.87	16.15	13.39	13.83
Dairy	306.58	324.33	279.89	331.15	294.85
Eggs	27.69	28.94	26.03	26.29	23.55
Meat	119.00	130.35	121.42	130.40	95.65
Seafood	84.34	75.24	67.58	73.57	54.31
Ready meals	29.13	37.76	42.99	42.18	30.98
Sweets	23.09	21.47	20.76	19.40	24.02
Oils	44.77	40.08	36.90	34.99	38.96
Sauces	5.12	5.23	5.70	6.53	8.34
Beverages	193.63	199.38	291.16	289.62	299.14
Total	1517.76	1584.25	1590.69	1655.58	1538.13
Food category	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**
	kg CO_2·inhabitant^{-1}·day^{-1}				
Fruits	67.02	66.55	63.84	66.30	64.84
Vegetables	176.12	195.65	196.50	210.94	183.15
Starch-based products	152.66	153.24	157.84	156.64	148.12
Legumes	5.63	5.75	5.67	5.28	5.15
Nuts	7.31	8.63	8.95	7.45	7.70
Dairy	598.37	607.06	611.91	641.52	712.53
Eggs	49.84	52.10	46.85	47.32	42.39
Meat	965.65	916.81	752.84	863.94	753.54
Seafood	477.50	432.69	379.53	427.32	272.53
Ready meals	124.77	157.80	177.91	176.54	129.19
Sweets	15.11	13.79	13.23	12.50	14.59
Oils	55.22	49.29	46.19	44.05	49.40
Sauces	9.50	9.74	10.56	12.03	15.29
Beverages	142.96	143.69	208.38	209.18	219.51
Total	3.16	3.13	2.98	3.20	2.91

CHAPTER 7

Efficiency assessment of diets in the Spanish regions: a multi-criteria cross-cutting approach[11]

SUMMARY

Food systems are one of the main drivers of the global greenhouse gases emissions from anthropogenic sources, which could be aggravated by the projected increase in world population. Hence, the adoption of sustainable diets that guarantee good and accessible nutrition and a low environmental impact is an increasingly important need. This goal is, by nature, a multi-dimensional and multi-criteria challenge that should take into account nutritional, environmental and socioeconomic aspects. In this sense, Chapter 7 proposes a novel methodological framework that involves the use of Data Envelopment Analysis for the efficiency assessment of dietary patterns integrating nutritional (Nutrient Rich Diet 9.3 index), environmental (carbon footprint) and socioeconomic criteria (number of deaths due to tumors of the digestive system, obesity-related health expenditure, and number of persons with food shortages). The applicability of this methodology is proven through the case study of the dietary patterns of the 17 Spanish autonomous regions. The analysis reveals the existence of seven autonomous regions with sustainable dietary patterns. Furthermore, most regions have multi-criteria efficiency scores above 0.60, which suggests the presence of relatively good dietary habits in Spain. Overall, it is concluded that the proposed methodology is a viable and valuable tool for benchmarking dietary patterns under multiple cross-cutting criteria.

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[11] Esteve-Llorens, X.[a], Martín-Gamboa, M.[b], Iribarren, D.[c], Moreira, M.T.[a], Feijoo, G.[a], Gonzalez-García, S.[a], 2020. Efficiency assessment of diets in the Spanish regions: a multi-criteria cross-cutting approach. J. Clean. Prod. 242: 118491. ISSN: 0959-6526. https://doi.org/10.1016/j.jclepro.2019.118491.

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CHAPTER 7 - OUTLINE

7.1. INTRODUCTION

In addition to a low environmental impact, the variables that a diet must meet to be considered as sustainable are several, as mentioned in Chapter 2. In this sense, the main characteristics of a sustainable diet are: an associated low environmental impact; ensuring food safety and security and therefore, being protective and respectful of biodiversity and ecosystems; accessible and economically fair; and affordable (FAO and WHO, 2019).

Bearing in mind the concept of sustainable diet (FAO and WHO, 2019), the Mediterranean diet is widely recognized as an example, since it is a plant-based diet with a moderate intake of animal-based products (Castañé and Antón, 2017). It is the most widespread traditional consumption pattern in Spain, along with other suitable variations such as the Atlantic diet, located mainly in the northwest of the Iberian Peninsula (Leis Trabazo et al., 2019), which has been previously analyzed in Chapter 3. However, it is important to note that current consumption patterns deviate from the traditional Mediterranean recommendations (Batlle-Bayer et al., 2019; González-García et al., 2020), including some types of foodstuffs that are not advisable, such as industrially processed food (AECOSAN, 2021; MAPA, 2021).

Moreover, socioeconomic factors, such as lifestyle, along with marketing and economic issues, are also important when talking about access to safe and secure food consumption patterns (Pechey and Monsivais, 2016). Consumption habits differ regionally depending on cultural preferences and levels of development (González-García et al., 2018). Food cost is a relevant contributor to socioeconomic patterns of diets, since foods rich in energy and of lower nutritional quality tend to be cheaper; moreover, higher quality diets are often associated with higher food expenditures(Wrieden et al., 2019). In addition, more educated consumers usually make healthier food purchase (Handbury et al., 2015).

Therefore, the achievement of sustainable diets is, by nature, a multi-dimensional and multi-criteria challenge as mentioned in Chapter 2. The measurement of sustainability should take into consideration nutritional, environmental and socioeconomic aspects in order to ensure well-being and quality of life without increasing impacts on the environment. Furthermore, this measurement is particularly relevant when a high variability of dietary patterns is observed, even between regions within the same country. However, a lack of comprehensive but practical metrics to measure the multiple aspects of sustainable diets has hampered progress towards analyzing the influence of new guidelines and implementing relevant policies (Jones et al., 2016). Along with the development of well-defined and interdisciplinary criteria and metrics on the sustainability of diets, the need for tools that collectively accounts for this set of criteria is increasingly evident. Among the tools available to achieve this goal, Data Envelopment Analysis (DEA) is a linear programming tool to evaluate the relative efficiency of a number of homogenous entities (Cooper et al., 2007). Within the context of this chapter, this efficiency could be understood as a composite index that jointly interprets the sustainability of dietary patterns under multiple criteria. This research aims to enrich the current literature on sustainability assessment of diets by developing and applying a methodological framework for the efficiency assessment of dietary patterns under multiple cross-cutting criteria. In particular, the Spanish dietary patterns from 2016 are considered as case study to test the feasibility of the methodology. To this end, the Spanish regions (17 autonomous regions) are analyzed and benchmarked taking into account nutritional, environmental and socioeconomic criteria. Beyond this specific case study, the proposed methodological approach is generally relevant to the multiple-criteria assessment of the efficiency of dietary patterns regardless of the geographical scope (regional/national/international).

7.2. MATERIALS AND METHODS

Differences in diets available worldwide are associated with variations in the aspects surrounding them, such as economic, social and environmental factors (González-García et al., 2018). Moreover, within the same country there may also be variations between regions, taking into account different cultural, lifestyle and climatic features, as is the case in Spain (MAPA, 2020). In these circumstances, a methodological framework is developed herein to evaluate the multi-criteria efficiency of diets, including the factors mentioned above. Its feasibility is proven by applying it to the 17 Spanish autonomous regions.

7.2.1. SPANISH DIETARY HABITS ACROSS REGIONS

It is well-known that the Mediterranean diet is traditionally the one with the highest percentage of adherence in Spain. Additionally, it coexists with other lesser-known dietary patterns such as the Atlantic diet, located in north-western Spain (Leis Trabazo et al., 2019). However, adherence to these traditional diets is shifting towards the so-called western diet, with higher consumption of animal products, processed food, and lower intake of plant-based foods than recommended (Batlle-Bayer et al., 2019; Blas et al., 2019). Furthermore, the great differences that exist at both climatic and cultural levels in Spain also cause a variation between regional patterns of food consumption. In this sense, the type and amount of food differs among the 17 autonomous regions (MAPA, 2021).

7.2.2. METHODOLOGICAL FRAMEWORK FOR THE EFFICIENCY ASSESSMENT OF DIETS

The methodological approach proposed for the multi-criteria efficiency assessment of diets is summarized in Figure 7.1. The methodological structure presented here is a variant of the three-stage Life Cycle Assessment (LCA) + DEA method proposed by Lozano et al. (2010). In particular, the list of criteria included in the analysis is extended beyond the implementation of life-cycle indicators (Martín-Gamboa et al., 2017). In this regard, a nutritional quality index and socioeconomic criteria are also taken into consideration to offer a holistic vision in terms of sustainability. As shown in Figure 7.1, the first step of the methodological framework refers to data acquisition for socioeconomic indicators, as well as for the compilation of inventories needed to assess the carbon footprint (CF) and the nutritional quality index of the annual dietary patterns of the 17 average citizens (i.e., one average citizen per autonomous region). The socioeconomic indicators chosen in this study are the following: number of deaths from tumors of the digestive system, obesity-related health expenditure and number of people with food shortages. The selection of these indicators is based on their ability to represent health, economic and social aspects closely related to dietary habits in Spain. A more explanation of these indicators is provided later in Section 7.2.3.4. The second step of the proposed methodology focuses on the calculation of the CF and the nutritional quality index, as detailed in Sections 7.2.2.1 and 7.2.2.2, respectively.

The final stage involves the use of DEA as a tool for the multi-criteria efficiency evaluation of the dietary habits of the 17 autonomous regions in Spain. The usefulness of this approach for reporting a sustainability index has already been tested in the energy sector (Martín-Gamboa et al., 2019). For the present case study, the dietary habits of the average citizen of each Spanish autonomous region constitute the set of homogenous entities under assessment, also called decision making units (DMUs). In the DEA step, a data matrix (see Section 7.3.3) is processed to compute the efficiency scores of the dietary patterns of the Spanish regions. These multi-criteria efficiency scores can be understood as a composite index that jointly accounts the sustainability of Spanish dietary patterns under multiple cross-cutting aspects.

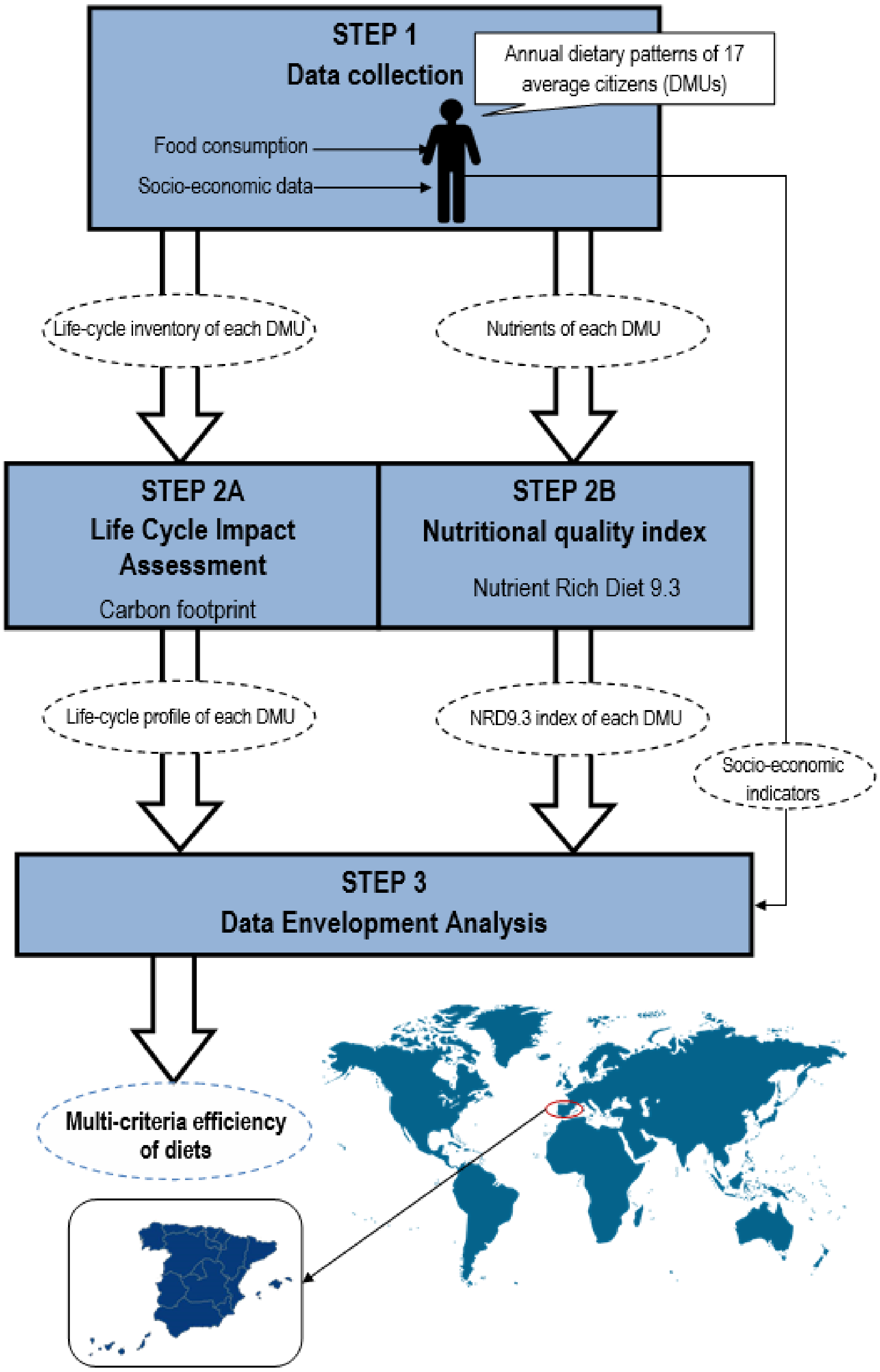

Figure 7.1. Methodological framework for the multi-criteria efficiency assessment of diets.

7.2.2.1. CARBON FOOTPRINT OF DIETS

As mentioned in section 2.2 form the Chapter 2, the CF is selected for the estimation of the environmental impact of the dietary patterns under study. In this sense a life cycle approach is used for this purpose and the detailed information about the methodology can be seen in the aforementioned section from the Chapter 2. Bearing in mind that the main objective is to evaluate the efficiency of diets considering the multiple criteria associated with the dietary patterns of the Spanish autonomous regions, in this LCA study only the production phase of food products is considered in line with Chapter 6. In fact, this stage is the main source of greenhouse gases (GHG) emissions in dietary patterns as reported in Chapter 3, and according to the literature, generating around 70% of them (Batlle-Bayer et al., 2019; González-García et al., 2020), and where the greatest variations may exist between the different regions analyzed and the food consumed. Other stages such as transport, household activities and waste disposal, are omitted because minor fluctuations are expected between the autonomous regions within a country. Therefore, the LCA approach follows a cradle-to-gate perspective.

The functional unit selected for this study refers to the foodstuffs purchased by the average citizen of each Spanish region for household consumption on an annual basis. Therefore, it is a caloric-independent functional unit that only takes into account the annual consumption per person of food in the different Spanish regions to compare the impacts between different dietary habits from the autonomous regions. This amount is extracted directly from the household consumption survey carried out by the Spanish Ministry of Agriculture, Fisheries and Food (MAPA, 2021) as explained later in Section 7.2.3.

7.2.2.2. NUTRIENT RICH DIET 9.3

The widely recognized Nutrient Rich Diet 9.3 (NRD9.3) index, proposed by Van Kernebeek et al. (2014), is selected to estimate nutritional quality in line with previous chapters. This index is based on the difference between nine nutrients to encourage and three nutrients to limit, and their link to daily reference values. The complete information about this index can be found in section 2.3.2 from Chapter 2.Concerning the Recommended Daily Values (*RDV*) and Maximum Daily Values (*MDV*) required for the estimation, they are taken from Codex Alimentarius (FAO/WHO, 2017).

7.2.2.3. DEA FOR MULTI-CRITERIA EFFICIENCY ASSESSMENT

The slacks-based DEA model proposed by Tone (2002) is used herein to calculate the multi-criteria efficiency of dietary patterns. The analysis includes 17 DMUs corresponding to the 17 average citizens of the Spanish autonomous regions, taking 2016 as the reference year. Every DMU is characterized by four inputs (i.e., deaths from tumors of the digestive system, obesity related health expenditure, number of people with food shortages, and CF) and one output (the NRD9.3 index). The selection of the DEA elements takes into account not only the goal of the study (sustainability assessment of diets in terms of multi-criteria efficiency), but also the recommendations available for the combined LCA + DEA studies (Iribarren et al., 2016), which refer to features such as quantifiability, specificity, availability and quality. In this context, DEA is a linear programming methodology that non-parametrically calculates the comparative efficiency of multiple similar entities (DMUs), and projects the inefficient DMUs at the efficient frontier, thereby providing target values for the inefficient entities into efficient ones (Cooper et al., 2007). A more extensive and detailed description of the methodology is given in section 2.4 of Chapter 2, also including the corresponding equations.

The choice of an input-oriented model aims to reduce inputs and ensure at least the same output (i.e., the same nutritional quality). Solving the optimization problem results in the efficiency score (Φ) of each dietary pattern linked to the average citizen of each Spanish autonomous region. Efficiency scores lead to discriminate between efficient ($\Phi = 1$) and inefficient ($\Phi < 1$) dietary habits. It should be noted that these efficiency scores act as an index that brings together the different selected criteria to provide a single measure of sustainability of the dietary habits currently present in Spain. In this sense, a single score measurement rather than multiple criteria may facilitate the formulation of guidelines and policies based on the best-performing dietary habits identified within the set of entities under assessment.

7.2.3. Data acquisition

7.2.3.1. Dietary patterns in the Spanish autonomous regions

The information on the current consumption habits in the 17 autonomous regions that constitute the Spanish territory comes from the survey of household food demand, performed by the Spanish Ministry of Agriculture, Fishery and Food (MAPA, 2021). As mentioned in Chapter 6, the methodology followed in these surveys is based on daily data collected at the household level through a scan of their food purchases, with a total sample of 12,000 households distributed across the regions. Thus, in the selected households, foodstuffs purchases were recorded daily through a code reader and collected in a monthly sample, covering all possible seasonal variations in consumption; as a result, the average amount of food consumed per person and year was directly obtained (kg food·person^{-1}·year^{-1}). This quantity, without modification, is directly used for the estimation of both the CF and the nutritional quality of Spanish dietary patterns. It should be borne in mind that in the aforementioned database a large amount of information on the food consumed is provided. In summary, a total of 101 foods considered as the most representative (see Table 7.1) are grouped into 15 different food categories (i.e., fruits, vegetables, starch-based products, legumes, nuts, dairy, eggs, meat, seafood, canned food, ready meals, sweets, fats/oils, sauces, and beverages).

Table 7.1. Amount of food eaten per person and year in each autonomous region (kg·person-1·y-1).

FOOD CATEGORY	ANDALUSIA	ARAGÓN	ASTURIAS	BALEARIC ISLANDS	CANARY ISLANDS	CANTABRIA	CASTILE AND LEÓN	CASTILE-LA MANCHA	CATALONIA	VALENCIAN COMMUNITY	EXTREMADURA	GALICIA	COMMUNITY OF MADRID	REGION OF MURCIA	CHARTERED COMMUNITY OF NAVARRE	BASQUE COUNTRY	LA RIOJA	MEAN
FRUITS	83.16	102.7	115.6	88.4	92.7	94.9	113.1	86.8	99.4	84.5	84.0	109.23	94.4	84.67	111.4	112.4	77.2	96.12
VEGETABLES	85.2	86.2	95.78	85.78	90.3	77.78	80.6	77.2	101.01	91.0	84.2	93.3	83.0	88.6	93.8	89.8	68.3	86.6
STARCH BASED PRODUCTS	51.4	51.2	66.5	49.3	49.6	53.8	62.5	58.4	51.1	52.6	52.3	65.6	45.8	50.9	61.6	59.9	53.7	55.7
LEGUMES	2.7	3.5	4.2	2.7	2.8	3.6	2.8	2.8	3.6	2.9	3.1	2.4	2.6	2.8	2.9	3.4	2.7	3.0
NUTS	4.2	6.2	5.6	5.5	4.8	4.3	4.5	4.4	6.9	5.3	4.6	4.8	4.5	4.6	4.5	4.5	4.3	4.9
DAIRY	91.9	103.6	129.5	81.9	99.5	100.5	124.3	108.1	86.2	90.6	110.7	115.7	95.5	90.6	107.7	100.7	100.7	102.2
EGGS	7.7	10.1	9.9	7.7	7.4	10.1	9.6	8.2	7.9	8.4	7.5	7.9	7.6	7.2	8.9	9.3	8.5	8.5
MEAT	39.2	49.3	47.4	35.6	31.8	40.1	51.2	45.3	41.9	41.8	40.8	45.6	39.9	39.0	42.0	41.9	41.1	42.0
SEAFOOD	17.6	21.7	25.5	14.3	14.3	22.1	25.6	19.7	20.1	18.5	17.5	27.7	19.9	15.9	18.6	23.8	19.4	20.1
CANNED FOOD	15.8	15.6	16.4	13.0	15.0	16.4	16.5	17.4	14.1	15.2	17.0	15.5	15.6	15.9	14.1	17.6	14.2	15.6
READY MEALS	10.9	11.4	10.4	10.0	9.6	9.9	9.9	11.1	14.0	11.3	10.5	6.2	11.7	10.6	8.2	9.3	13.0	10.5
SWEETS	6.2	7.0	10.1	7.3	9.1	7.4	8.8	7.4	6.9	7.0	7.3	10.9	6.1	7.4	7.5	7.7	8.3	7.7
OILS/FATS	11.3	12.2	15.7	11.5	13.0	14.9	14.9	9.7	11.9	9.0	10.2	17.6	10.7	8.6	10.2	13.5	14.3	12.3
SAUCES	1.9	1.5	1.9	1.3	2.4	2.1	1.6	2.0	1.3	1.5	2.0	1.3	1.4	1.9	1.7	1.6	1.3	1.7
BEVERAGES	91.5	64.6	67.8	82.1	90.5	55.3	63.6	91.5	73.9	75.1	79.5	69.0	74.8	83.9	62.8	62.9	53.2	73.1
TOTAL	521.3	547.2	622.3	496.4	532.5	512.9	589.6	550.1	540.2	514.7	531.1	592.7	513.7	512.5	555.8	558.4	480.1	539.5

Food consumption outside of households is not considered in this study due to the scarcity of data, as well as specifications at the level of foodstuffs. In fact, about 92% of food consumption takes place at home (MAPA, 2018).

7.2.3.2. Nutritional composition

The nutritional composition of the foodstuffs included in the study is obtained from the Spanish Food Composition Database (AECOSAN, 2021). It provides complete nutritional information on a wide variety of foods, thus covering all the information necessary for estimating the nutritional quality index (i.e., micronutrients and macronutrients). The complete nutritional composition according to the amount of food consumed in each autonomous region can be found in Table 1 of the Appendix. In addition, the energy content of the foodstuffs is also extracted from this database in order to determine the total caloric ingestion of the consumption patterns.

7.2.3.3. Data for carbon footprint assessment

Regarding the data used to estimate the CF, a total of 33 LCA studies (see Table 2 of the Appendix) are used to provide information on the life-cycle GHG emissions associated with the production of the different foodstuffs included in the surveys reported by the Spanish Ministry of Agriculture, Fishery and Food (i.e., 101 products with their respective CF and grouped in the corresponding food category). Due to the wide variety of available LCA studies and the variation of results among them (Berners-Lee et al., 2012; Clune et al., 2017; Werner et al., 2014), moderately conservative values are selected as far as possible. The foodstuffs are evaluated from a cradle-to-gate perspective, according to the system boundaries of this study. In this sense, although the vast majority of the selected LCA studies keep the established system boundaries, there are a few ones that incorporate additional stages, such as transport, storage or waste management. In these cases, the corresponding GHG emissions associated with these stages are subtracted. Furthermore, in some cases certain foodstuffs are assimilated to others due to the lack of data to determine their environmental impacts (e.g., nectarines as peaches, milkshake as milk, cured cheese as Galician cheese, and biscuits as cereals).

7.2.3.4. Socioeconomic data

The holistic vision of sustainability is completed with the selection of three socioeconomic indicators: number of deaths from tumors of the digestive system, obesity-related health expenditure and number of people with food shortages. This choice derives from the application of the available guidelines for the selection of socioeconomic indicators in sustainability oriented LCA + DEA studies (Iribarren et al., 2016). In this sense, the three selected indicators fulfil the requirements in terms of quantifiability, availability, quality, and specificity to the DMU (i.e., the average citizen of each autonomous region). Table 7.2 presents the data corresponding to these indicators expressed for the total population of each autonomous region. The first indicator involves a health and social issue and encompasses all deaths from tumors associated with the digestive tract (such as tumors of the esophagus, stomach and colon). In this sense, up to 30% of all cancer cases worldwide are linked to poor dietary habits, reaching 70% for cancers of the gastrointestinal tract. The second socioeconomic indicator indicates the health expenditure of each autonomous region due to obesity, an issue closely linked to bad dietary habits, Finally, the third socioeconomic indicator includes the number of people per autonomous region who cannot afford a meal of meat, chicken or fish at least once every two days. These data are retrieved from the annual statistics available in the Spanish National Statistics Institute database (INE, 2021).

Table 7.2. Socioeconomic indicators (data for the total population of each Spanish autonomous region).

DMU	Number of deaths from tumors of the digestive system	Health expenditure related to obesity (M€)	Number of people with food shortages
Andalusia	4224	618.24	218,629
Aragón	962	125.92	22,373
Asturias	971	105.95	49,645
Balearic Islands	523	98.78	10,358
Canary Islands	951	186.72	284,450
Cantabria	447	56.30	6396
Castile and León	2173	229.84	34,102
Castile-La Mancha	1272	183.78	93,883
Catalonia	4313	594.36	215,793
Valencian Community	2865	413.87	143,117
Extremadura	732	109.65	14,008
Galicia	2286	245.05	29,811
Community of Madrid	3279	525.75	77,720
Region of Murcia	695	122.79	64,811
Chartered Community of Navarre	380	69.50	1921
Basque Country	1620	245.18	43,346
La Rioja	219	25.60	12,192

7.3. RESULTS AND DISCUSSION

7.3.1. CARBON FOOTPRINT OF DIETS

The CF results for the 17 Spanish autonomous regions range from the lowest value for Balearic Islands with 905 kg CO_2 eq·person^{-1}·year^{-1} to the highest one for Asturias with 1195 kg CO_2 eq·person^{-1}·year^{-1}, as displayed in Figure 7.2. It is a remarkable variation of 290 kg CO_2 eq·person^{-1}·year^{-1}, which can be translated into 0.79 kg CO_2 eq per person and day. It is observed that there are significant differences between regions within the same country. The rationale behind them may be associated with differences in climate (e.g., results from Chapter 6), culture and lifestyle, which derive into the consumption of foodstuffs in different quantities and with different regularity. However, a common pattern is that about 80% of the GHG emissions come from meat, dairy products, seafood, beverages and starch-based products. Within these categories, meat and dairy products stand out, contributing to 50% of the total GHG emissions. In this way, variations in the quantity and proportions of these food categories are largely responsible for the fluctuations in CF between the Spanish regions. The remaining 10 food categories only contribute about 20% of GHG emissions.

Figure 7.2 displays not only the CF results per region, but also the proportions of the above-mentioned 5 main categories. As can be observed, the regions in north-western Spain are those with the highest CF figures. In this sense, the average citizens of Asturias, Galicia and Castile and León present CFs associated to their dietary patterns of 1195, 1170 and 1158 kg CO_2 eq·person^{-1}·year^{-1}, respectively. On the contrary, the regions located in the south and east of Spain involve the lowest CF values, these being 905, 926, 944 and 968 kg CO_2 eq·person^{-1}·year^{-1} for the average citizens of the Balearic Islands, the Region of Murcia, Andalusia and the Valencian Community, respectively. Significantly higher consumption of meat, dairy products and seafood is the main cause of a higher CF in the north-western regions. Thus, Asturias, Castile and León and Galicia consume on average 28%, 19% and 37% more meat, dairy and seafood respectively, than the Balearic Islands, the Region of Murcia, Andalusia and the Valencian Community (see Table 7.1). Furthermore, the higher CF figure is also related to a higher caloric intake (see Figure 7.3); thus, although the diet energy content does not vary much between the Spanish regions, the ones with the highest CFs are those with the highest energy intakes (Asturias, Castile and León, and Galicia).

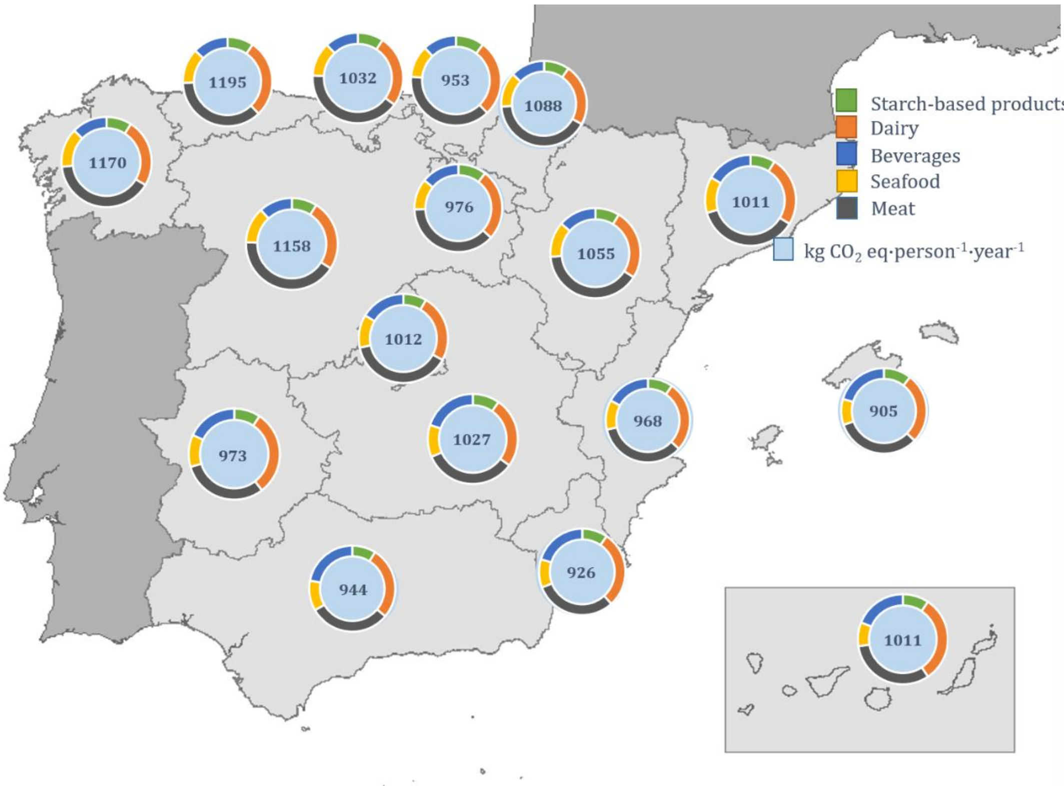

Figure 7.2. Carbon footprint of diets for each Spanish autonomous region.

Other studies from the literature reported different results in terms of CF for dietary patterns existing in Spain. Comparison between them should be prudent due to the great variability of data sources used for the collection of life cycle inventory data, as well as to the different origin of food consumption data. In this way, when reviewing other studies, it is observed that both higher and lower CF values coexist in the country. Castañé and Antón (2017) and González-García et al. (2020) reported 735 and 845 kg CO_2 eq·person^{-1}·year^{-1} for the Mediterranean diet respectively; and results from Chapter 3 of the Atlantic diet was 842 kg CO_2 eq·person^{-1}·year^{-1} (only considering the production stage in the three scenarios). They are remarkably low values in comparison with the Spanish average CF obtained in the present case study (1024 kg CO_2 eq·person^{-1}·year^{-1}). The rationale behind this finding is that in these studies the ingestion of the recommended daily food quantities was considered following the Mediterranean and Atlantic patterns; additionally, beverages were not included in their scope of application. Thus, when studies based on real consumption patterns are analyzed, the proportions and quantities of certain food categories change considerably (e.g., higher consumption of livestock products and processed food), and consequently the CF also varies. Thus, the CF reported by Batlle-Bayer et al. (2019) and Sáez-Almendros et al. (2013) for the average Spanish dietary patterns is 1120 and 1350 kg CO_2 eq·person^{-1}·year^{-1}, respectively. These values are closer to the ones reported in our study for the regions with the highest CFs. Finally, even higher values can be found for the Galician region such as 1752 kg CO_2 eq·person^{-1}·year^{-1}

respectively considering only the production stage of the results from Chapter 4 for the Galician diet.

7.3.2. NUTRIENT RICH DIET 9.3 SCORES

In terms of nutritional quality results, Catalonia obtains the best NRD score (371), followed by the Basque Country (370), Navarre (364) and the Valencian Community (360). On the contrary, the lowest nutritional quality indices correspond to the dietary habits from Castile-La Mancha (329), La Rioja (331) and Andalusia (332). The differences between the regions with the highest and lowest nutritional quality are moderate (≈12%).

A higher intake of fiber, vitamin C, potassium and magnesium is the main cause of the better nutritional quality of the diets in Catalonia, the Basque Country, Navarre and the Valencian Community (see Table 1 of the Appendix). In this regard, increased intake of fiber, vitamin C, potassium and magnesium intake is directly related to a higher consumption of plant-based foodstuffs (fruits, vegetables, legumes, and nuts). Thus, when comparing NRD9.3 scores from Catalonia and Castile-La Mancha, it can be observed that the consumption of fruits and vegetables is 13% and 25% higher in the former region, respectively. Likewise, the Basque Country consumes 23% and 14% more fruit and vegetables than in Castile-La Mancha (see Table 7.1). Attending to nuts consumption, it is 23% and 18% higher in Catalonia and Basque Country respectively than in Castile-La Mancha. The consumption of other nutrients considered in the index, such as the harmful ones (saturated fats, sodium, and free sugar), remains relatively stable in all regions (see Table 1 of the Appendix). In this specific case, the consumption of saturated fats and free sugars is above the recommended upper limit by 30% and 60% respectively on average for all regions. It is mainly caused by excessive consumption of non-advisable products such as sweets, ready meals, processed food, and soft drinks. On the contrary, sodium intake remains below the upper recommended limit, on average.

Figure 7.3 presents the complete list of NRD9.3 scores by region and its relationship to the caloric ingestion. In Figure 7.3, the Spanish regions are ordered in decreasing order according to their NRD9.3 result, while the diet energy content of each of them remains around an average value of 1900 kcal per person and day.

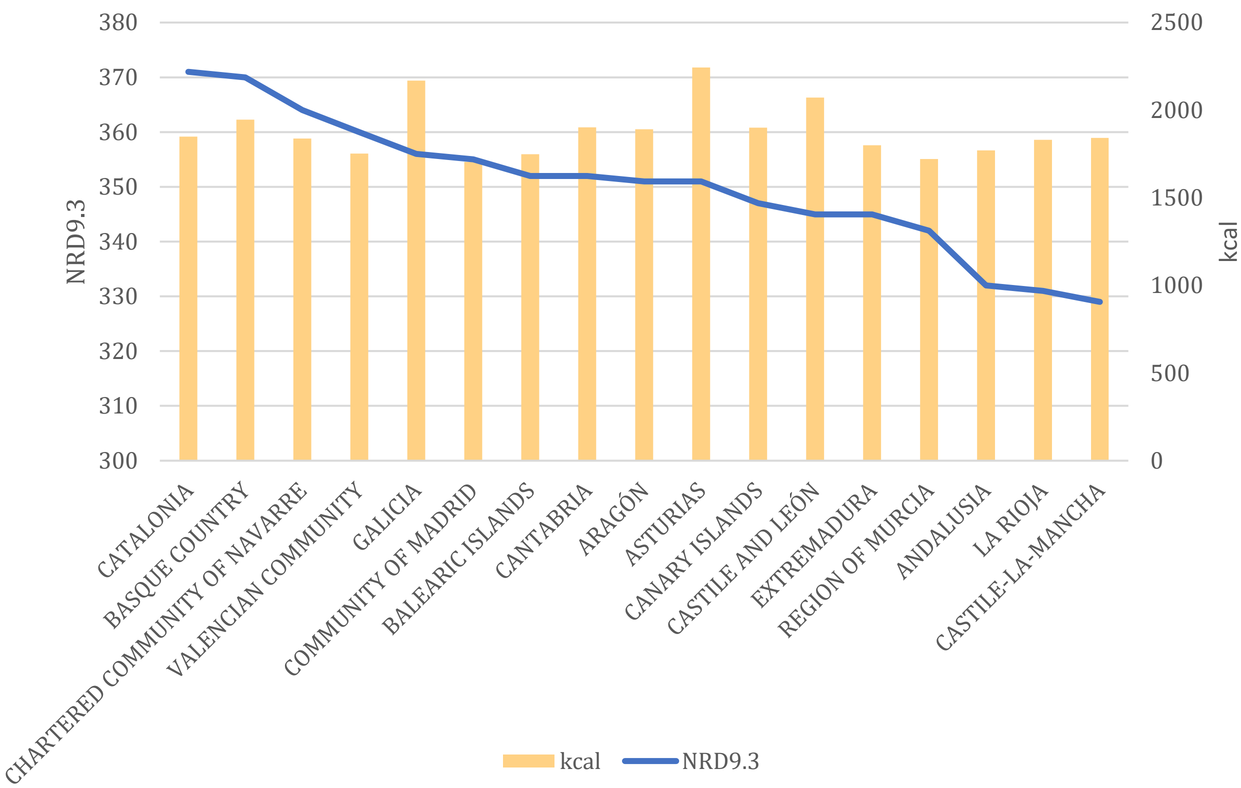

Figure 7.3. Nutritional Rich Diet 9.3 (NRD9.3) scores, combined with the caloric intake per Spanish autonomous region.)

As can be observed in Figure 7.3, although the energy intake remains stable around a mean value, the nutritional quality decreases from the highest value in Catalonia to the lowest in Castile-La Mancha. This is directly related to the origin of energy ingestion: the greater the amount of energy coming from plant-based and low-processed foodstuffs, the higher the nutritional quality of a diet. Conversely, if an important part of the energy comes from processed food and sweets, among others, the nutritional quality is negatively affected. This is the case of Catalonia and Castile-La Mancha: the amount of fruit and vegetables consumed in the former is 20% higher than in the latter, whereas the inhabitants of Castile-La Mancha consume 10% more meat and 5% more processed food (e.g., sweets, sauces, and soft drinks).

7.3.3. MULTI-CRITERIA EFFICIENCY SCORES

After the calculation of the CFs and the nutritional quality index associated with the dietary patterns of the average citizens of the Spanish autonomous regions, DEA is carried out to compute their efficiency scores and, subsequently, to identify the Spanish regions with the best-performing dietary patterns according to the selected criteria. Thus, the DEA study involves a comparison of the dietary patterns of the average citizens of the Spanish autonomous regions in terms of relative efficiency. Further comparative studies –e.g., at the international level– would require additional data and are out of the scope of this study. Table 7.3 presents all the input and output data that make up the DEA matrix needed to computationally calculate the multi-criteria efficiency scores. Following the trends observed in the CF results, the Balearic Islands, Andalusia, and the Region of Murcia are among the autonomous communities with the lowest number of deaths due to tumors of the digestive system (allocated to each average citizen), while Asturias presents the highest value. In the case of obesity-related health expenditure, the average expenditure per person in Spain is 91 euros, with the highest expenses in Navarre and the Basque Country and the lowest in Andalusia. Regarding food shortages, the case of the Canary Islands is highlighted, with a value significantly higher than those of the rest of the autonomous regions. Given the high variability of findings involved in the analysis, the use of DEA is convenient to collectively interpret all the information through a single sustainability (relative efficiency) index. Thus, the DEA matrix is implemented in the SBM-I-VRS model for the estimation of the multi-criteria efficiency scores using the DEA-Solver Pro software (SAITECH, 2021).

Table 7.3. DEA matrix (data attributed to the average citizen of each Spanish autonomous region).

DMU	Number of deaths from tumors of the digestive system	Health expenditure related to obesity (€)	Number of people with food shortages	Carbon footprint (kg CO_2 eq)	NRD9.3
Andalusia	$5.02\cdot10^{-4}$	73.50	$2.60\cdot10^{-2}$	943.85	332.03
Aragón	$7.31\cdot10^{-4}$	95.70	$1.70\cdot10^{-2}$	1054.93	350.82
Asturias	$9.39\cdot10^{-4}$	102.40	$4.80\cdot10^{-2}$	1195.15	351.42
Balearic Islands	$4.54\cdot10^{-4}$	85.80	$9.00\cdot10^{-3}$	904.53	351.95
Canary Islands	$4.41\cdot10^{-4}$	86.60	0.13	1010.60	346.76
Cantabria	$7.69\cdot10^{-4}$	96.80	$1.10\cdot10^{-2}$	1031.83	351.57
Castile and León	$8.92\cdot10^{-4}$	94.40	$1.40\cdot10^{-2}$	1158.17	345.03
Castile-La Mancha	$6.23\cdot10^{-4}$	90.00	$4.60\cdot10^{-2}$	1027.38	328.82
Catalonia	$5.80\cdot10^{-4}$	79.90	$2.90\cdot10^{-2}$	1010.63	370.57
Valencian Community	$5.81\cdot10^{-4}$	83.90	$2.90\cdot10^{-2}$	968.42	360.44
Extremadura	$6.79\cdot10^{-4}$	101.80	$1.30\cdot10^{-2}$	973.28	345.16
Galicia	$8.44\cdot10^{-4}$	90.40	$1.10\cdot10^{-2}$	1169.54	355.94
Community of Madrid	$5.06\cdot10^{-4}$	81.20	$1.20\cdot10^{-2}$	1012.50	355.09
Region of Murcia	$4.72\cdot10^{-4}$	83.40	$4.40\cdot10^{-2}$	926.34	342.09
Chartered Community of Navarre	$5.93\cdot10^{-4}$	108.50	$3.00\cdot10^{-3}$	975.63	364.17
Basque Country	$7.47\cdot10^{-4}$	113.10	$2.00\cdot10^{-2}$	1088.16	369.84
La Rioja	$7.01\cdot10^{-4}$	81.90	$3.90\cdot10^{-2}$	953.42	330.81

As a result, Figure 7.4 shows the multi-criteria efficiency scores obtained for the dietary patterns of the 17 autonomous regions. Seven of these regions have suitable (i.e., efficient) dietary habits under the set of criteria chosen, with efficiency scores Φ of 1. These regions with the best-performing patterns correspond to Andalusia, the Balearic

Islands, the Canary Islands, Catalonia, the Community of Madrid, Navarre, and the Basque Country. Furthermore, all the autonomous regions, with the exception of Asturias, show multi-criteria efficiency scores above 0.60 and the average efficiency score of the sample is 0.84, which indicates the presence of relatively good dietary habits in Spain. This fact could be motivated by the great influence of the Mediterranean diet in practically all the autonomous regions of Spain. In the case of Asturias, which presents the lowest efficiency score (Φ = 0.57), the relatively low score may be linked to the high amounts of meat consumed in this region.

The analysis of the potential relationship between multi-criteria efficiency and certain parameters of interest (such as meat intake, average income, and unemployment rate) does not show clear trends, except in the case of low intakes of meat. In this regard, the lowest meat consumption levels within the sample are found to be always associated with efficient dietary patterns. However, it should be noted that efficient dietary habits do not always imply low meat consumption.

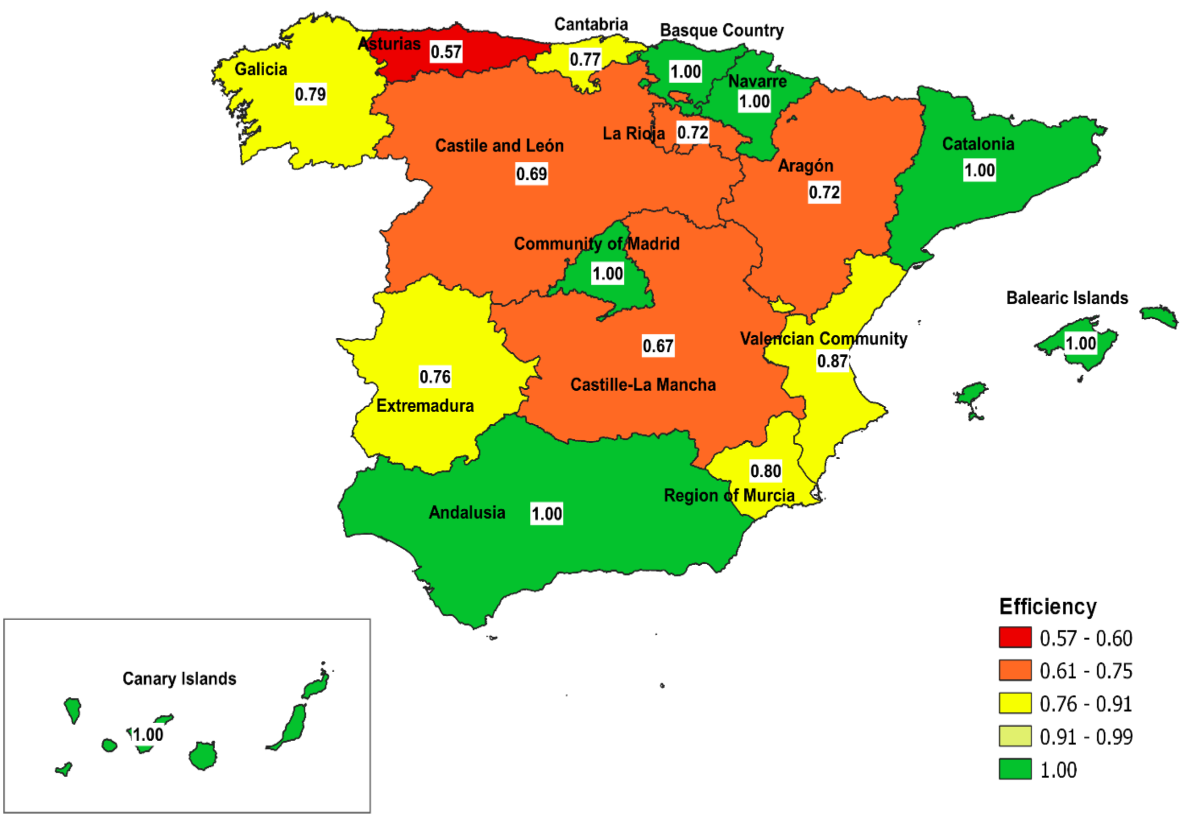

Figure 7.4. Efficiency scores of regional dietary patterns in Spain.

Given the high number of autonomous regions deemed efficient, a super-efficiency analysis is also carried out to further discriminate among the efficient dietary patterns in Spain (Iribarren et al., 2010). The implementation of a super-efficiency DEA model is highly recommended within this context, ranking efficient DMUs by assigning efficiency scores greater than 1. An input-oriented slacks-based measure of super-efficiency model with variables return to scale (Super-SBM-I-VRS) is used for the discrimination between the efficient dietary patterns (Tone, 2002). Through this analysis, the average citizen of Navarre is identified as the best-performer reference, followed at a distance by the Canary Islands and Catalonia. This more accurate identification of the best-performers can be especially useful to decision- and policy-makers when it comes to setting benchmarks as reference or target values towards sustainable diets.

7.4. Conclusions

The set of criteria chosen in this study served as valuable metrics for measuring the sustainability efficiency of dietary patterns associated with a set of regions. In this sense, the collection of socioeconomic data and the calculation of the carbon footprint and the Nutrient Rich Diet 9.3 index provided significant insights into how sustainable the dietary habits in Spain are. In order to interpret in a combined way these multiple cross-cutting criteria, the coupled use of DEA within the methodological framework proposed in this work proved to be feasible and valuable for the sustainability efficiency assessment of dietary habits. The application of this methodological framework to the case study of dietary patterns in Spain allowed the identification of seven regions with the most suitable dietary patterns according to the selected sustainability criteria. In fact, all the Spanish autonomous communities, except one, presented multi-criteria efficiency scores above 0.60, which concludes the presence of relatively good dietary habits in Spain. This finding is probably motivated by the great influence of the Mediterranean nutritional patterns in all Spanish regions. In particular, through a super-efficiency analysis, Navarre emerged as the region of reference when it comes to setting sustainable dietary habits. Overall, beyond the case study of Spain, the proposed methodology could contribute to defining sound guidelines and policies based on the performance of regions with efficient (i.e., sustainable) dietary patterns.

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APPENDIX

Table 1. Daily nutritional composition for the 17 autonomous regions and Recommended Daily Value (RDV)/Maximum Daily Value (MDV)

	Protein	Fiber	Vit A	Vit C	Vit E	Ca	Fe	K	Mg	Sat. Fat	Na	Free sugar
	g	g	µg	mg	mg	mg	mg	mg	mg	g	mg	g
RDV/MDV	50	25	800	100	9	1000	22	3500	310	20	1950	50
Andalusia	73.4	17.6	531.1	123.8	11.6	754.0	10.5	2579.1	233.1	25.4	1843.7	77.5
Aragón	84.7	19.7	554.9	138.3	14.0	826.9	11.6	2885.4	255.8	28.2	1853.5	80.7
Asturias	94.4	23.4	603.8	156.1	16.0	1014.2	13.1	3288.6	289.5	31.9	2204.9	96.1
Balearic Islands	68.9	18.8	541.7	124.9	12.6	729.2	10.0	2542.9	231.9	24.6	1600.3	75.9
Canary Islands	71.5	20.0	645.2	141.4	13.1	871.4	10.4	2680.8	248.5	28.0	1807.9	86.0
Cantabria	79.2	19.4	557.5	135.3	14.1	815.1	11.1	2689.4	240.7	27.5	1843.8	75.0
Castile and León	91.8	20.9	589.9	154.3	15.7	917.8	12.1	3041.8	269.6	30.0	2048.1	89.2
Castile-la Mancha	80.9	18.5	520.4	129.0	11.7	821.1	11.0	2701.0	246.3	26.6	1982.6	82.2
Catalonia	79.2	20.4	564.9	142.9	12.3	776.3	11.8	2868.4	255.1	26.4	1781.4	76.8
Valencian Community	77.9	18.6	554.4	122.8	11.3	783.8	11.0	2659.8	243.9	25.4	1768.7	74.3
Extremadura	77.9	18.3	543.6	129.7	11.8	851.7	10.6	2679.0	244.8	26.5	1889.7	77.9
Galicia	90.5	22.5	591.9	160.0	18.8	926.9	12.8	3116.3	281.0	30.1	1981.9	93.3
Community of Madrid	74.1	18.2	549.8	135.8	10.6	760.6	10.5	2648.5	235.5	25.0	1700.1	74.7
Region of Murcia	74.0	18.0	515.9	126.8	10.9	774.9	10.5	2585.4	237.3	25.2	1800.4	75.7
Chartered Community of Navarra	79.6	21.2	582.5	158.8	12.4	833.8	11.3	2898.4	252.2	25.4	1899.1	84.1
Basque Country	82.6	21.6	596.4	155.6	13.4	830.3	11.9	2940.9	261.2	27.0	1930.5	81.3
La Rioja	76.8	17.7	507.3	116.9	13.7	791.6	10.4	2483.6	226.4	27.0	1827.7	72.5
Mean	79.9	19.7	561.8	138.4	13.2	828.2	11.2	2781.7	250.2	27.1	1868.5	80.8

Table 2. Complete list of the 101 products included in the diets and their corresponding carbon footprint.

Food Category	Product	kg CO_2 eq/kg product
Fruits	Oranges	0.15
	Mandarins	
	Lemons	
	Bananas	0.30
	Apples	0.12
	Pears	0.12
	Peaches	0.12
	Nectarines	0.12
	Apricot	0.13
	Strawberries	0.33
	Melon	0.24
	Watermelon	0.24
	Plums	0.43
	Cherries	0.48
	Grapes	0.12
	Kiwis	0.33
	Avocados	1.30
	Pineapples	0.95
	Others	0.50
Vegetables	Tomatoes	0.22
	Onions	0.24
	Garlics	0.39
	Cabbages	0.24
	Cucumber	0.30
	Green beans	0.23
	Peppers	0.22
	Mushrooms	4.42
	Lettuce	0.24
	Asparagus	0.24
	Spinach	0.54
	Eggplant	0.30
	Carrots	0.23
	Zucchini	0.30
	Others	0.47
	4th range	0.97

Table 2. (continued)

Food Category	Product	kg CO_2 eq/kg product
Starch-based products	Potatoes	0.24
	Bread	0.67
	Rice	1.66
	Pasta	0.45
	Pastries	2.50
	Biscuits	4.00
	Cereals	4.00
Legumes	Chickpeas	0.77
	Beans	0.23
	Lentils	1.03
Nuts	Olives	3.66
	Almonds	0.23
	Peanuts	0.62
	Walnut	0.88
	Hazelnut	0.23
	Pistachios	0.53
	Others	0.62
Dairy	Milk	1.23
	Milkshake	1.23
	Yogurt	1.77
	Butter	7.20
	Cheese	10.44
	Ice-cream	2.80
	Custard	2.15
Eggs		1.80
Meat	Beef	28.60
	Chicken	3.00
	Lamb	10.85
	Pork	3.42
	Processed meat	3.42

Table 2. (continued)

Food Category	Product	kg CO_2 eq/kg product
Seafood	Hake	6.26
	Sardine	0.36
	Tuna	1.56
	Trout	2.70
	Sole	2.26
	Cod	2.43
	Mackerel	0.80
	Salmon	3.76
	Sea bass	3.55
	Gilt-head bream	2.26
	Turbot	14.51
	Monkfish	9.38
	Others	4.41
	Clams	1.28
	Mussels	1.59
	Squids	3.86
	Prawns	14.85
	Others	4.41
Canned food	Vegetables	4.25
	Fruit	1.85
	Fish	5.70
Ready meals	Preserved	10.00
	Frozen	6.00
	Soups/creams	0.48
	Pizza	6.00
Sweets	Chocolate	1.00
	Honey	0.23
	Sugar	1.00
Oils/fats	Olive oil	2.10
	Sunflower oil	0.76
	Margarine	1.66
Sauces	Ketchup	1.12
	Mayonnaise	1.95
Beverages	Wine	2.05
	Beer	1.55
	Juice	0.67
	Soft drinks	1.97

CHAPTER 8

Could the economic crisis explain the reduction in the carbon footprint of food? Evidence from Spain in the last decade[12]

SUMMARY

Dietary patterns are influenced by numerous external factors such as cultural taste and customs, nutritional and economic aspects and lifestyle and consumer preferences. Otherwise, food also causes a great impact on the environment and there can be a large difference between choosing certain foodstuffs, such as plant or animal-based ones. The key for an environmentally friendly and healthy diet is the high consumption of plant-based products, low amounts of animal-origin foodstuffs and limited quantity of refined grains, processed food and added sugars. Nevertheless, adherence to them has been decreasing over the years due to the adoption of a more westernized consumption pattern. Thus, the main goal of this chapter is to monitor the food consumption patterns at household level during a period of 10 years (2008-2017), selecting Spain as case study. Both the impacts that foodstuffs included in the food basket cause in the environment, and the socio-economic variables that influence the consumer choice are considered. Results show a generalized decrease of the carbon footprint over the years. However, it does not always mean an approach to a healthier diet, considering that in this case it decreases both the consumption of those foods with a greater environmental footprint as those essential for a balanced diet with low ecological impact. Additionally, there is also an increase in the consumption of processed food, which further distances the dietary pattern from the recommendations, what can be more pronounced for the most vulnerable population groups, with less purchasing power to access healthy food.

[12] Esteve-Llorens, X.[a], Moreira, M.T.[a], Feijoo, G.[a], González-García, S.[a], 2021. Could the economic crisis explain the reduction in the carbon footprint of food? Evidence from Spain in the last decade. Sci. Total Environ. 755:142680. ISSN: 0048-9697. https://doi.org/10.1016/j.scitotenv.2020.142680.

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CHAPTER 8 - OUTLINE

8.1. INTRODUCTION

A diet is a set of foodstuffs that make up our eating habits, which are the result of conscious behavior, collective in most of cases and always repetitive. Accordingly, that behavior leads to select, prepare and consume these foodstuffs as one of the parts of social and cultural customs, being influenced by multiple factors such as society, economy or geography (FEN, 2013). Nevertheless, these consumption habits can exert a huge pressure on our environment which is considerably affected by the selected foodstuffs (e.g., animal-based vs plant-based). This issue is also relevant bearing in mind that by 2050 the world population will be near 10 billion people and as consequence, the food demand could increase around 70% (United Nations, 2019a).

As mentioned in previous chapters, current dietary patterns are generally far from dietary guidelines so they are strongly based on the consumption of animal-origin products and processed food (Blas et al., 2019). Also globalization of the food system and changes in population's lifestyle such as more consumption out-of-home and less time cooking make this gap more relevant (Smith et al., 2013). In the case of Spain, food consumption patterns have moved towards a more westernized diet, including the high dependence on animal-origin products and the low intake of plant-based foodstuffs (Abellán Alemán et al., 2016; Castañé and Antón, 2017). This has led to an increase in the incidence of food diseases in Spanish society such as obesity and other chronic diseases like cancer and cardiopathies (Ruiz et al., 2015).

In the same way that our decisions affect the environment, external factors might modify our dietary choices. Financial and economic crises increase unemployment and impoverishment of families. In this sense, the economic recession significantly emphasize the changes in household consumption habits (Muñoz Sánchez and Pérez Flores, 2015; Serra-Majem and Castro-Quezada, 2014). Thus, the prices of the foodstuffs are a determining factor in their choice, making an impediment to access to healthy food. Bearing in mind the main findings from Jones et al. (2014), healthy food is more expensive than less one (mainly because of the higher prices of fruit and vegetables) making healthier diets less affordable. Consequently, facing a rise in food prices and a decrease in purchasing power can lead to a replacement of more nutritionally dense products with less healthy ones rich on calories such as prepared dishes (Wiggins et al., 2015). In addition, a reduction in daily nutrient intake can mean a deficiency of micro and macronutrients intake by the most vulnerable population such as children, pregnant women or people with chronic diseases (de Pee et al., 2010). Conversely, another study reported some beneficial effects derived from the financial downturn, especially in adult population, such as weight loss in healthy population and reduction of mortality from diabetes and coronary heart diseases (Franco et al., 2013). Taste, perceived nutrition and costs can influence the food preferences at individual level, while a change in the food supply chain, an increase of the out-of-home eating trend, the promotion of healthy food, marketing and education are examples of environmental factors influencing the consumers' behavior.

In recent years, there has been an extensive proliferation of research related to the study of the environmental and nutritional impacts of food consumption patterns throughout the world (González-García et al., 2018). As indicator for the assessment of the environmental impact, the carbon footprint (CF) has been widely used in these research studies (Batlle-Bayer et al., 2019; González-García et al., 2020) among others such as water footprint or land use change (Blas et al., 2019; Castañé and Antón, 2017). Nevertheless, as far as it is known there are no previous studies relating CF and socioeconomic indicators in the economic recession period.

Therefore, the main goal of the present chapter is to monitor the food consumption pattern at household level during a period of 10 years (2008-2017), selecting Spain as case study. This period is considered interesting since it includes the hardest years of the last economic crisis, in which the country was severely affected; for instance, from 2008 to 2013, the average household income decreases from 29,634 to 26,174 euros per year, and the unemployment rate goes from 8% to the historical maximum of 27% (INE, 2021). Having said this, the motivation of the study is thus the possible relationship between the economic crisis and the environmental impact of a food consumption pattern, which can bring knowledge to a field that has not been studied so far. Both the impacts that foodstuffs included in the food basked cause in the environment, and the socioeconomic variables that influence the consumer choice are considered. For this purpose, CF is selected as environmental indicator, while unemployment rate, Consumer Price Index (CPI) of food, poverty risk rate and deaths associated to tumors in the digestive system constitute the socioeconomic variables that will be used in the present study. Section 8.2 describes the databases that contain information on food consumption and socioeconomic data for Spain; in addition, the process for the calculation of the CF is also mentioned. Then, the results and discussion section (i.e., section 8.3) includes the setting of the tipping points for the 2008-2017 period resulting from the integration of all the indicators; secondly, the socioeconomic-environmental nexus is evaluated, and finally, the level of compliance with the traditional recommendations over the years is discussed. This methodological framework is displayed in Figure 8.1.

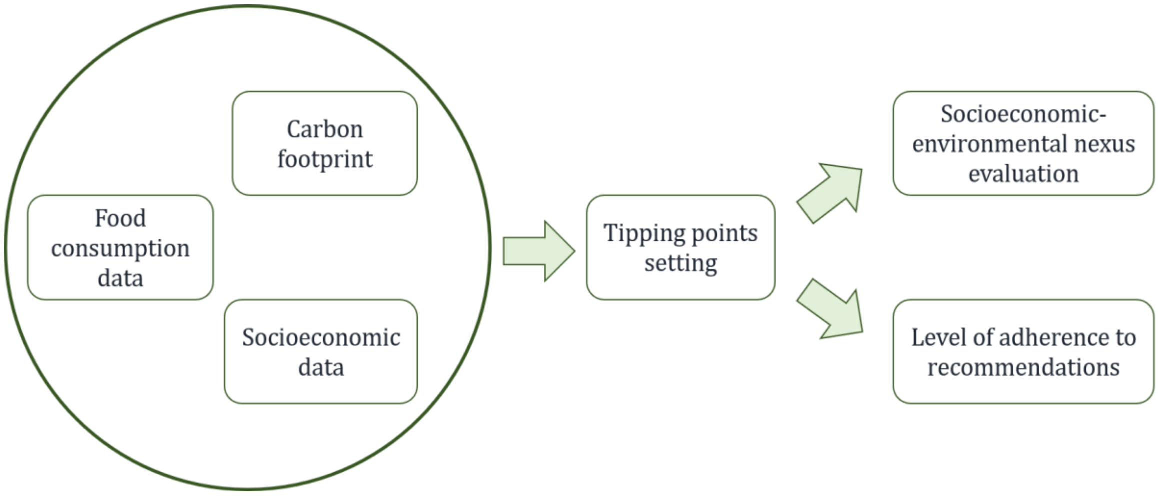

Figure 8.1. Flow diagram of the main steps followed to carry out the study.

8.2. MATERIALS AND METHODS

8.2.1. SPANISH CONSUMPTION HABITS

Food consumption data from 2008 to 2017 have been subtracted from the Household Food Consumption Panel of the Spanish Ministry of Agriculture Fishing and Food (MAPA, 2021), in line with Chapters 6 and 7. The present database aims at meeting the direct demand for food at the Spanish households by systematically collecting information on what Spaniards buy for household consumption, the corresponding expenditures per foodstuff and where foodstuffs are bought. As mentioned in Chapters 6 and 7, the sample consists of about 12000 households randomly selected from a universe of about 18 million homes that make up the territory. In this sense, household food purchases are recorded daily as a survey and finally collected in monthly series. The different variables of the survey (purchased product and quantity, expense of the total purchase, unit price and type of establishment in which the purchase was made) are acquired using an optical barcode reader (MAPA, 2021).

For the present case study, average annual consumption data are required, so the units are expressed in terms of kilograms of food purchased per inhabitant and year, which allows its direct use for the estimation of the CF. The household food consumption panel offers a very detailed breakdown about all the consumed items; however, they have been grouped into a total of 104 most representative foodstuffs and 14 different categories (i.e., fruits, vegetables, starch-based products, legumes, nuts, dairy, eggs, meat, seafood, ready meals, sweets, fats/oils, sauces, and beverages). Complete information about quantities of food consumed per year within the studied period can be found in Table 1 of the Appendix.

One of the limitations of this database is that out-of-home consumption has been left out of the study since detailed information about this food consumption along the selected period is not available. Although the objective of the present study is to check the food consumption trends at household level, providing the information regarding food consumption out of them would be a great contribution; in this sense, it could be verified if the population tends to exert a greater out-of-home consumption with the passage of the years and also the effect that the economic crisis has on this consumption, since it would be expected to be reduced (Muñoz Sánchez and Pérez Flores, 2015).

8.2.2. CARBON FOOTPRINT ASSESSMENT

The CF scores associated to the Spanish food consumption habits for the 2008-2017 period are evaluated from a Life Cycle Assessment (LCA) approach (ISO, 2006) under a cradle-to-gate perspective in line with the approach of the Chapters 6 and 7; in this way, only the GHG emissions from the production stage are considered, taking into account production stage is by far the one which has the greater environmental impact (ca. 70% of the total GHG emission from the food chain (Batlle-Bayer et al., 2019; Corrado et al., 2019; Esteve-Llorens et al., 2019b, 2019a), the main objective of this chapter is to detect variations in terms of CF and consequently where the greater magnitude fluctuations can exist. Consequently, the remaining stages, such as transport, retailing, consumption or waste management has been left out of the scope also taking into account that this exclusion does not affect the relative comparison between the different years of the period although some cooking methods may have varied over the years (e.g., cooked foods vs ready meals). The purchased amount of food per inhabitant and year (kg food·inhabitant^{-1}·year^{-1}) is selected as Functional Unit (FU), and it is directly taken from Spanish Ministry of Agriculture, Fishing and Food survey, previously mentioned in Section 8.2.1 (MAPA, 2021).

Regarding the data acquisition for the evaluation of the CF, a total of 31 LCA studies have been selected for the extraction of information on GHG emission derived from the production of each foodstuff that makes up the Spanish dietary pattern (i.e., 104 products from household's surveys). This methodology largely builds on that from the Chapter 7, and complete information about individual CF of the foodstuffs is displayed at Table 2 of the Appendix**.**

8.2.3. SOCIOECONOMIC DATA

The basis for sustainable development is the balance between society, economy and environment. Thus, socioeconomic indicators, together with environmental ones, are reflecting the health of a region (United Nations, 2019b). Similarly, a diet is considered as sustainable when it causes the minimal impact on the environment, is healthy and economically affordable (FAO and WHO, 2019). As mentioned above, consumers' choices cause an environmental impact, with greater or lesser extent, depending on the foodstuffs they include in their food basket, and in the same way, different variables (e.g., economy and society) can influence on the consumers' decisions. Consequently, to evaluate this connection, a set of socioeconomic variables have been selected (i.e., unemployment rate, household food expenditure corrected according to the CPI of food, poverty risk rate and deaths associated to tumors in the digestive system). The selection of these variables has been made accounting to their ability to reliably represent social and economic aspects of Spain throughout the period under study.

The source of information for these indicators has been the National Statistics Institute (INE) database from Spain (INE, 2021). The complete socioeconomic data for each year can be found in Table 8.1. Additionally, figures about consumption habits have been also used for the evaluation (i.e., consumption frequency of fruits, vegetables, legumes, meat, processed meat, sweets and soft drinks). In this case, the source is the National Health Survey elaborated by the Spanish Ministry of Health, Consumption and Social Welfare in collaboration with the INE (INE, 2021) and it provides information about how many times per week the mentioned items are consumed (i.e., daily, three times per week, twice a week, once a week or rarely). The figures are associated to 2006, 2011 and 2017, when the surveys were conducted, and can be seen in Table 3 of the Appendix. With this information, the level in which dietary habits approach to recommendations for a healthy diet can be determined according to Spanish Federation of Nutrition (FEN, 2013).

Table 8.1. Socioeconomic information for the 2008-2017 period.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Unemployment rate	9.6	17.24	19.84	21.08	24.19	26.94	25.93	23.78	21	18.75
Consumer price index (CPI)	92.874	91.898	91.13	93	95.164	97.816	97.475	98.619	100	101.23
Δ Consumer price index (%)	5	-1.1	-0.8	2.1	2.3	2.8	-0.3	1.2	1.4	1.2
Beef cost (€/kg)	8.84	8.99	8.82	9.03	9.04	9.07	9.17	9.2	9.18	9.42
Poverty risk rate (inhabitants %)	19.80	20.40	20.70	20.60	20.80	20.40	22.20	22.10	22.30	21.60
Deaths from digestive system tumors (deaths·year^{-1})	35368	35975	37633	38273	38774	39014	39004	39038	39774	39471
Household Food Expenditure (€)	1714	1633	1603	1604	1617	1617	1603	1649	1654	1650
Household Food Expenditure corrected with CPI (€)	1815	1615	1590	1637	1654	1663	1598	1669	1677	1670
Out-of-home food expenditure (€)	1171	1100	1050	1045	979	908	948	1038	1115	1206
Out-of-home food expenditure corrected with CPI (€)	1240	1088	1042	1067	1001	933	945	1051	1131	1221

8.3. Results and discussion

8.3.1. Tipping points

The results of the different indicators considered in the present study are obtained for each year included in selected period (2008-2017). However, bearing in mind that the main objective is to monitor the food consumption pattern at Spanish household level during this period, special attention has been paid to certain tipping points (TP). In these points, a series of changes or disruptions in the trends becomes significant enough to cause larger and more important changes; consequently, the indicators evolve in a different direction. Thus, four main TP have been identified throughout the period as can be observed in Figure 8.2. They are detailed below, as well as the main disruptions which cause trend changes.

- TP0: It has been set at the beginning of the period under assessment (2008) as reference point from which the first symptoms of the economic downturn begin to be visible. In this year, the CF and household food expenditure are at the highest level of the entire period. Additionally, unemployment rate has the lowest value of the period (see Table 8.1). Poverty risk rate and deaths associated to tumors of the digestive system are placed in the lowest positions of the period (see Table 8.1).

- TP1: It is in one of the hardest years of the Spanish economic recession (2010). The rationale behind this is that there is a drastic descent of household food expenditure and the increase of unemployment rate during the previous years, followed by a notable drop in the purchased amount of food and CF. Another reason why the TP1 is placed in this year is the subsequent smoothing of the slope in Figure 8.2 and stabilization of these parameters. Poverty risk rate is also stabilized during the following years but conversely, the deaths associated with tumors in the digestive system progressively increase over the time.

- TP2: In 2013 there is another change in the trend of the indicators, so another tipping point is established in this year. At this point, the unemployment rate reaches its highest figure within the period and begins to progressively decrease by the following years. After 2013, household food expenditure tends to increase (See Figure 8.2) but on the contrary, purchased amount of food (Table SI-1 of the Supplementary Information) and CF begin to fall again. Poverty risk rate and deaths associated to tumors in the digestive system progressively increase in the next years.

- TP3: The last year of the period (2017) is set as the final TP. The unemployment rate continues its downward trend and CF reaches its lowest value of the period. Additionally, household food expenditure, poverty risk rate and deaths associated to tumors in the digestive system remain stable around the values of previous years.

8.3.2. EVALUATION OF THE SOCIOECONOMIC-ENVIRONMENTAL NEXUS

8.3.2.1. CARBON FOOTPRINT ASSESSMENT

The CF figures of the studied period ranges from 872 kg CO_2 eq·inhabitant^{-1}·year^{-1} at the last year of the period (2017) to 1036 kg CO_2 eq·inhabitant^{-1}·year^{-1} at the beginning of the period (2008). In this sense, the CF scores tend to decrease as the years go by with a reduction of around 16% between 2008 and 2017, which can be translated into 164 kg CO_2 eq, as can be observed in Figure 8.2. However, even though the general decrease, the trend is not lineal with the time as it has been mentioned previously in section 8.3.1. For this reason, considering the set TPs, three main sub-sections within the period can be delimited. First, there is a steep drop of the CF between TP0 and TP1; then, the CF slop decreases and stabilizes between TP1 and TP2; and finally, the decreasing trend becomes pronounced again between TP2 and TP3.

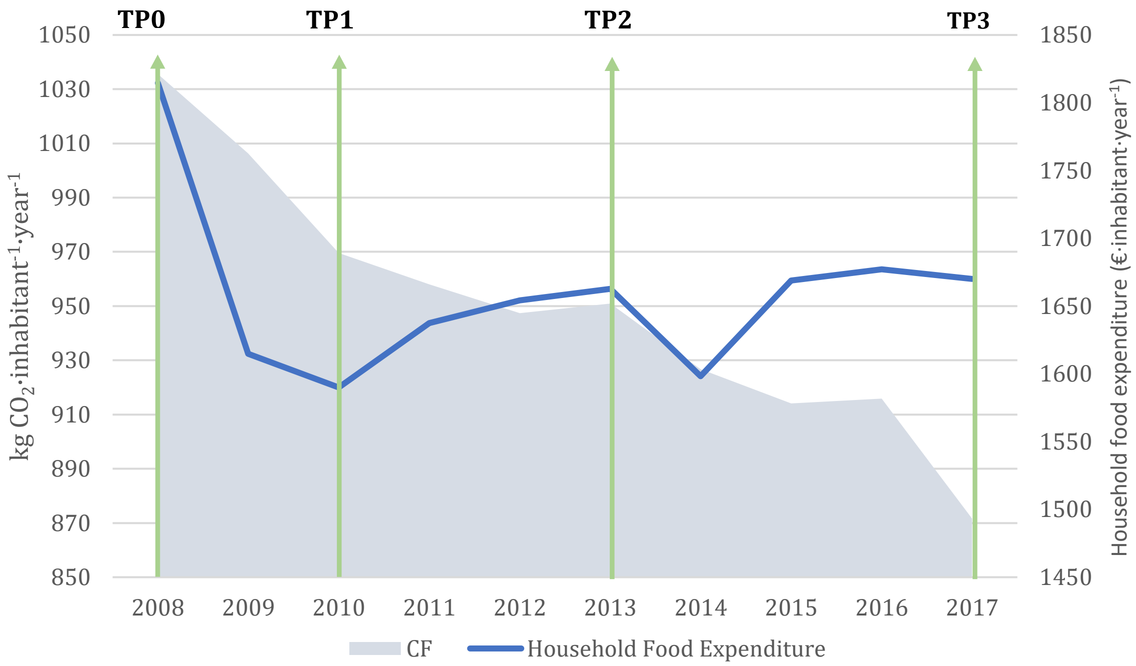

Figure 8.2. Dietary habits-based carbon footprint related to food expenditure per inhabitant and year. Green lines indicate the tipping points (TP) which are identified throughout 2008-2017 period

The reduction in the CF throughout the period can be mainly attributed to the decrease in the purchased amount of food which is around 10% lower (~62 kg of food) in TP3 than in TP0. Regarding this reduction, in the same way as the CF, the trend between TP0 and TP3 is not lineal throughout the period. There is a first drop in food consumption rate between TP0 and TP1 (~27 kg), followed by a stabilization and a small increase between TP1 and TP2 (~3kg). Finally, the most important decrease takes place (~37 kg), which is placed between TP2 and TP3.

When focusing on the reduction of food consumption rate, it is important to investigate certain food categories. According to the consulted data, there is a decrease of meat and seafood consumption from TP0 to TP3, owing to the large CF of these foodstuffs; hence, reducing the consumption of these products around 17% and 21% respectively leads to avoid the emission of around 140 kg CO_2 eq·inhabitant^{-1}·year^{-1}. Moreover, there is also an important reduction on the consumption of fruits, vegetables and starch-based products (mainly bread and potatoes) of 11%, 11% and 17% respectively. Nevertheless, the avoided emissions associated to these products are only about 14 kg CO_2 eq·inhabitant^{-1}·year^{-1}. Even though there is a general drop in the absolute value of consumed food in almost all food categories, it is not the case for ready meals category whose consumption increases about 18% from TP0 to TP3; consequently, it can be related to a changing lifestyle with less time spent cooking at home and a growing adherence to a westernized diet with the inclusion of more processed foodstuffs. Furthermore, lower household food consumption could be linked to a changing lifestyle and consequent growth in out-of-home food consumption (Smith et al., 2013), but due to the lack of detailed data about the latter consumption, the hypothesis has to be treated with caution.

Although the decrease of CF can be mainly attributed to the downward trend in household food consumption in terms of purchased quantities, the proportion in which the foodstuffs are consumed is another important factor that also causes significant fluctuations in the CF of dietary patterns. In this sense, it is well known that the replacement of certain foods with a high CF, such as beef meat (28.6 kg CO_2 eq·kg^{-1}) (Clune et al., 2017), for those with a lower impact such as plant-based products, can significantly contribute to the reduction of the corresponding CF (Willett et al., 2018). Bearing in mind this concept, the contributions of the main food categories (i.e., meat, dairy, seafood and beverages) to the CF vary depending on the TP. In this way, as it can be seen in Figure 8.3, despite meat products are one of the main contributors to the CF (>30%), their relevance decreases over the years, from 36% in TP0 to 31% in TP3, which can be attributed to the drop in beef meat consumption. The rationale behind this is that although the consumption of all types of meat decrease, beef meat does it in a more pronounced way as its consumption is reduced by about 40% between TP0 and TP3. Otherwise, the consumption of the remaining types of meat only is reduced by 10% on average. Regarding the dairy products trend, its contribution to the CF increases two points throughout the period because of the decreasing consumption of products with a relatively small CF such as milk (i.e., 1.23 kg CO_2 eq·kg^{-1}), for others with more resource-intensive production systems such as ice cream or butter (10.14 kg CO_2 eq·kg^{-1} and 2.80 kg CO_2 eq·kg^{-1} respectively). Contributions from seafood and beverages remain almost in the same proportion and stable over the years, and as far as other foodstuffs contribution concern, it increases three points from 24% in TP0 to 27% in TP3, mainly motivated for an increase in the consumption of ready meals and sweets. This should be related to a progressive loss of adherence to the Mediterranean diet at first motivated more notably by the economic downturn, as reported by Bonaccio et al., (2014) for the similar case study of Italy, and then by a possible change in Spaniards lifestyle and consequent fluctuation in the food consumption patterns.

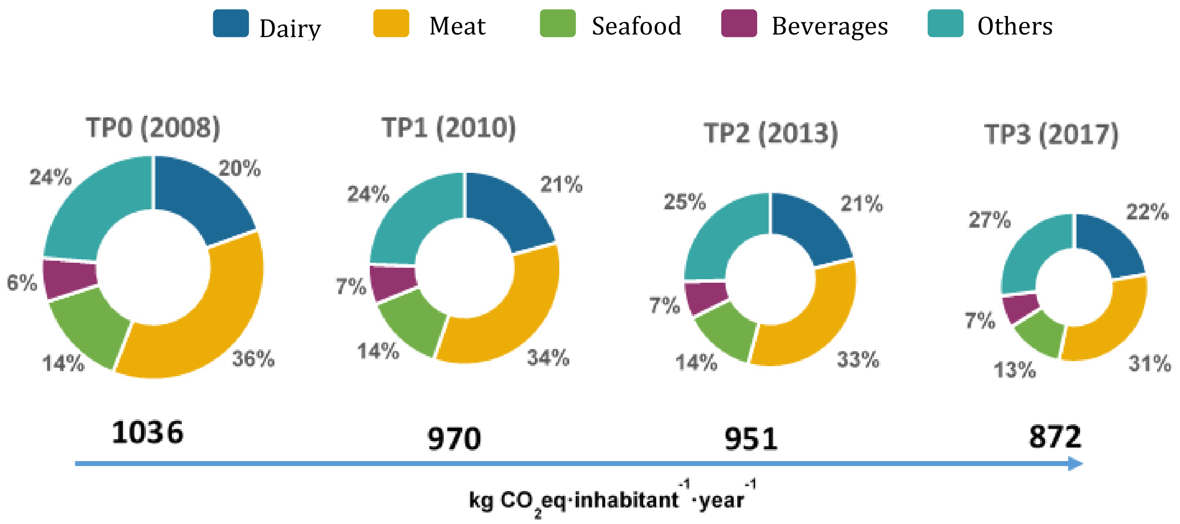

Figure 8.3. Distribution of the carbon footprint (%) from main food categories in the tipping points (TP) identified throughout the 2008-2017 period.

8.3.2.2. SOCIOECONOMIC-ENVIRONMENTAL NEXUS

There are strong evidences about the relation between changes in food dietary habits and financial crisis. Bonaccio et al., (2016) reported that that socioeconomic factors appear to be major determinants of the adherence to the Mediterranean diet, and consequently the adherence to this traditional dietary pattern has considerably decreased over the hardest years of the economic downturn (Bonaccio et al., 2014). Ásgeirsdóttir et al., (2014) concluded that the Icelandic crisis led to a significant reduction in health-compromising behaviors, such as drinking soft drinks and eating sweets, and certain health-promoting behaviors, such as the consumption of fruits and vegetables, but to an increase in other health-promoting behaviors such as fish and oil consumption. Otherwise, Serra-Majem and Castro-Quezada, (2014) refer to the effects that crisis has on the diet of the most vulnerable population groups. In this study, the aim is to relate socioeconomic variables with the CF of food consumption patterns, which as far as it is known has not been done before.

As it has mentioned before, the CF of the household Spanish dietary pattern decreases progressively over the years. In this sense, the main responsible cause is the least amount of food purchased by consumers. However, this may be related at the same time with the influence of certain pressures from socioeconomic parameters such as unemployment rate or CPI. As it can be seen in Table 8.1, unemployment rate progressively increases from TP0 to TP2, which matches with the first major decline and stabilization of the CF in the same period. Thus, a significant loss of purchasing power together with a general rise in food prices of around 5% in TP0 (see Table 8.1), may be behind this decrease in the purchased amount of food in this period. On the contrary, in the second part of the period (from TP2 to TP3) there is a moderate decrease in the unemployment rate. Nevertheless, despite the rise of the purchasing power, the CF continues decreasing until its lowest values in TP3 as previously mentioned. In this case a changing lifestyle could be the reason of CF and food amount drop, since over the years, it is increasingly common to eat out-of-home in addition to spending less time cooking; the increase of ready meals consumption during the study period could be a good indicator of this hypothesis. It would also be possible that the decrease in CF over the years was due to a more conscious consumption behavior of the consumers; nevertheless, the fact that there is general decrease in the purchased amount of almost all food groups and not only in those with higher CF makes the previous assumption more possible.

However, there is another hypothesis that supports the considerable decline of the CF from TP0 to TP3 and it is the continued decrease in the beef meat consumption. As it can be observed in Figure 8.4, beef consumption goes from about 9 kg·inhabitant^{-1}·year^{-1} to just over 5 kg·inhabitant^{-1}·year^{-1} in TP3. In this sense, when consumption is linked to its cost, it can be observed that the relationship is inversely proportional, considering that beef cost increases progressively from TP0 to TP3. In line with other studies (Wiggins et al., 2015), it would serve as proof of the influence of prices on the consumer choices. Furthermore, bearing in mind the huge impact of meat on the environment, and especially that of beef as it is well known, the application of specific rates to reduce their consumption could be considered by the policy makers as a valid solution to reduce GHG emissions from dietary patterns.

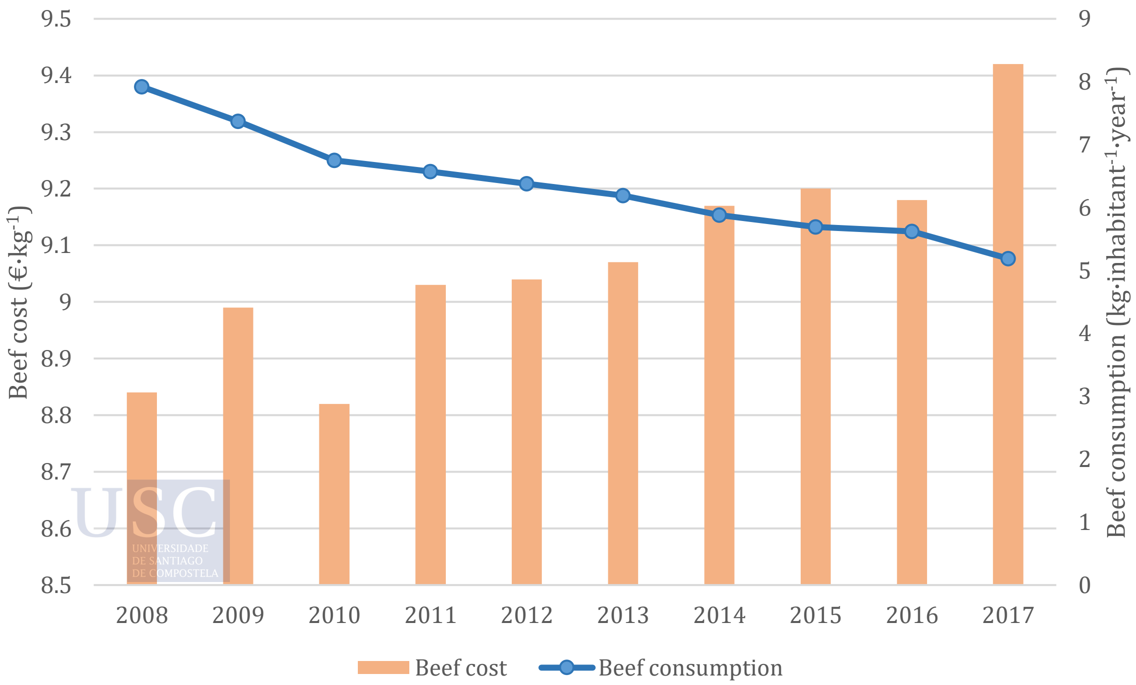

Figure 8.4. Relation between beef cost and its consumption over the period under study

Apart from the reduction in meat consumption, which could be considered as a good new, there is also a general decrease in the consumption of other basic food categories for a healthy and balanced diet such as fruits, vegetables, legumes, seafood, or certain type of fats (i.e., olive oil). These results are in line with Blas et al., (2019), who reported that current food dietary habits are far from recommendations; if this trend continues, the distance would be even greater since it is necessary to make the plant-based products the basis of the food pyramid and moderately consume those of animal origin and with a greater processing. This process of re-adherence to recommendations can be difficult if price of food or a decreasing purchasing power gets in the way. In this sense, when attention is paid to the poverty risk rate (see Table 8.1), it can be seen that it increases progressively from TP0 to TP3. Thus, despite the unemployment rate moderately decreases from TP2 to TP3, the poverty risk rate follows the opposite trend, which could mean a greater difficulty for the most vulnerable groups for access to healthy food.

Regarding future trends, consumer behavior could be expected to become more sustainable in the next years, given the growing concern for selecting more environmentally friendly food products (OCU, 2019). In this sense, there is an increase in the so-called committed consumers, which are characterized by 1) not buying more than necessary, 2) checking the origin and composition of the products, 3) recycling and seeking the minimum of waste and, 4) betting on proximity consumption. However, despite the willingness and commitment of many consumers, there are still many obstacles that prevent them from doing so more systematically, such as the lack of information, accessible alternatives or difficulties in finding responsible producers.

8.3.3. ADHERENCE TO RECOMMENDATIONS

In order to check the level of adherence to the sanitary recommendations throughout the studied period, this study uses the National Health Survey, carried out by the Ministry of Health, Consumption and Social Welfare with the collaboration of the National Statistics Institute (INE, 2021). Taking into account the information collected on the consumption frequency of certain food groups and the recommendations from SENC (see Table 3 of the Appendix) (FEN, 2013), the level in which consumption patterns approach to a healthy diet can be checked as it is presented in Figure 8.5. This chart represents the percentage of inhabitants that follows the recommendations for each included food category (i.e., fresh fruits, vegetables and salads, legumes, meat, processed meat, sweets and soft drinks).

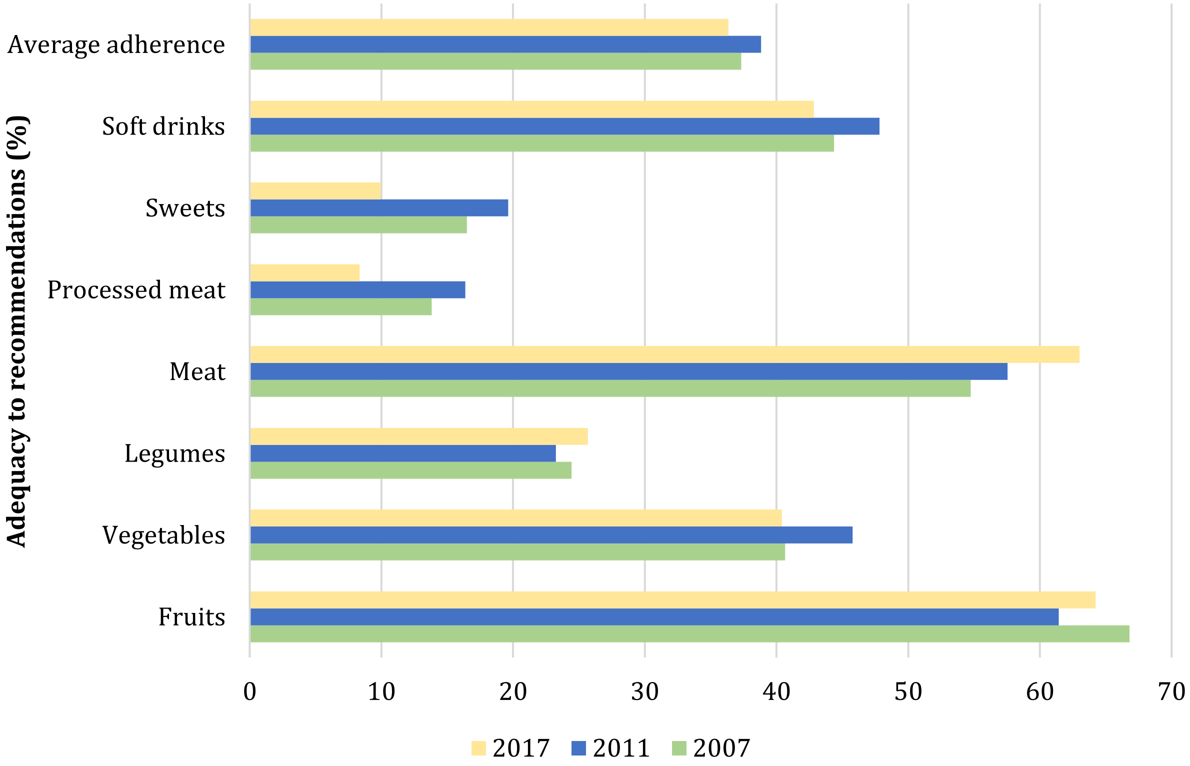

Figure 8.5. Level in which the consumption of fruits, vegetables, legumes, meat, processed meat, sweets, and soft drinks approach to health recommendations.

As it can be seen, the adherence level for fruit and vegetables consumption frequency, which should be consumed daily is not in the same direction. While the fruit consumption frequency decreases and moves away from recommendations, that from vegetables experiences the opposite effect. Regarding the legumes and meat, they should be consumed 3 times per week; in the case of the meat, it can be said that adherence to recommendations goes in the good directions, considering that near to 65% of inhabitants is decreasing its consumption frequency and consuming it in a more moderate way. It is not de situation for the legumes, whose consumption adherence decreases in the central years of the downturn and only increases a few points after this time. Regarding processed meat, sweets and soft drinks (not recommended), the trend is contrary to what might be expected, since in times of greater recession it is when there is a greater adherence to the recommendations, or what is the same, population reduce the frequency consumption of this foodstuffs. Finally, in terms of average adherence to recommendations, it should be highlighted that it increases in the central years of the downturn and declines again in the following years; these results can be related with those obtained by Ásgeirsdóttir et al., (2014) which reported that the Icelandic crisis led to a significant reduction in both health-compromising behaviors (e.g., drinking soft drinks and eating sweets) and health-promoting behaviors (e.g., consumption of fruits and vegetables), but to increase in other health-promoting behaviors such as fish and oil consumption.

Limitations of the study

One of the weakness of this study is that household food consumption data are not divided according to their purchasing power or income, so it is not possible to obtain the microdata from the surveys of the Spanish Ministry of Agriculture Fishing and Food. Thus different studies have proved that households with a lower income per capita have a diet richer in energy dense foods and those with a lower nutritional quality such as salty snacks, sweets or ultra-processed or fast food (Miqueleiz et al., 2014). On the contrary, household with a higher income level have a greater access to a balanced diet, closer to the traditional dietary recommendations and richer in highly nutritious plant-based foods such as fruit or vegetables. For this reason, future research will be focused on the study of the effects of income and other important indicators such as education level, gender and age, on the dietary patterns and their environment and health impacts. Moreover, as it has been mentioned before, there is no available detailed data about out-of-home food consumption, which could be very useful to check of the general decrease of the household food consumption is compensated with a larger out-of-home food ingestion. Additionally, this could also be useful to have a more comprehensive perspective of the Spanish dietary pattern evolution.

8.4. CONCLUSIONS

According to the main findings of this chapter, a decrease in the CF is not always synonymous with a healthier diet, since although the consumption of animal products decreases over the years, it also does that of some essential foodstuffs for a balanced a healthy diet such as fruits, vegetables or olive oil; on the contrary, there is also an increase in the consumption of ready meals and processed foodstuffs. This trend moves food habits away from traditional recommendations, which can be more pronounced for the most vulnerable population groups with an increase of the poverty risk rate and the difficulty of accessing to healthy food. It is for this reason why special attention should be paid to food security policies addressed to these segments of population. Otherwise, it also can be fathom from the results that the Spanish population is still far from being aware of the environmental impacts derived from food, considering the large number of animal-origin products that still today are part of the dietary pattern. Moreover, if the forecasts of a growing population awareness of adopting a more sustainable diet are met, the future effects on the environment and the health of the population's dietary patterns could be noticed in the short-medium term by taking advantage of the current downward trend of the CF. Future research activities will focus on verifying the adequacy of these forecasts in the coming years, including the effect of socioeconomic variables, such as income and education level, on out-of-home food consumption and the environmental impact derived from them, with different indicators such as water footprint and land use change.

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APPENDIX

Table 1. Quantities of foodstuffs consumed per capita and year (2008-2017)

		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
		kg·inhabitant^{-1}·year^{-1}									
Fruits	Orange	21.38	22.01	20.56	19.96	20	21.36	20.45	20.53	19.6	17.81
	Mandarin	6.92	6.69	6.51	6.68	6.91	6.52	6.57	6.43	6.26	5.63
	Lemon	2.16	2.29	2.16	2.26	2.27	2.29	2.32	2.45	2.42	2.56
	Banana	11.28	10.52	11.21	11.03	11.41	11.62	11.47	11.31	12.14	11.57
	Apple	12.95	12.55	12.12	11.95	11.61	10.98	11.12	11.29	10.87	9.85
	Pear	7.48	7.4	7.16	6.99	6.65	5.88	6.24	5.49	5.44	5.08
	Peach	5.19	5.06	4.8	4.39	4.45	4.22	3.99	3.73	3.79	3.48
	Nectarine	0	0	0	0	0	0	0	2.16	2.18	2.05
	Apricot	0.88	0.97	0.82	0.82	0.9	0.99	0.89	0.91	0.94	0.91
	Strawberry	2.58	2.77	2.4	2.51	2.82	3.05	2.97	2.45	2.95	2.55
	Melon	8.65	8.67	8.55	8.73	9.18	9.12	8.65	7.81	8.43	7.17
	Watermelon	7.41	7.43	7.94	7.59	8.71	8.87	8.46	8.64	8.66	8.4
	Plum	1.81	2.03	1.77	1.75	1.75	1.44	1.74	1.42	1.24	1.26
	Cherry	1.15	1.68	1.31	1.56	1.32	1.55	1.75	1.18	1.1	1.27
	Grape	2.12	2.34	2.25	2.42	2.21	2.36	2.25	2.39	2.08	2
	Kiwi	3.22	3.49	3.38	3.08	3.39	3.47	3.08	3.04	3.38	2.86
	Avocado	0.53	0.63	0.67	0.73	0.78	0.85	0.88	0.82	0.86	0.96
	Pineapple	1.96	1.87	1.9	1.91	2.01	1.86	2.1	1.76	1.74	1.79
	Canned	2.15	2.1	2.03	1.97	1.88	1.91	1.9	1.85	1.74	1.74
	Others	6.55	6.82	6.7	7.14	7.4	7.6	7.56	5.37	5.43	5.26
Vegetables	Tomato	14.87	15.08	14.14	15.24	14.82	15.05	14.29	13.98	14.22	12.83
	Onion	7.87	8.18	7.46	7.44	7.48	7.77	7.6	7.36	7.41	6.99
	Garlic	0.98	1	0.95	0.92	0.88	0.93	0.95	0.85	0.9	0.77
	Cabbage	2.12	2.04	1.98	1.91	1.99	1.98	1.85	1.85	1.58	1.55
	Cucumber	2.3	2.46	2.43	2.52	2.6	2.45	2.34	2.3	2.21	1.94
	Green beans	2.63	2.5	2.36	2.41	2.26	2.51	2.47	2.38	2.21	1.89
	Pepper	4.9	5.27	4.71	4.96	5.02	5.16	5.12	4.72	4.93	4.66
	Mushroom	1.17	1.17	1.24	1.31	1.32	1.39	1.37	1.24	1.3	1.22
	Lettuce	5.57	5.44	4.83	4.75	4.68	4.71	4.46	4.56	3.94	3.57
	Asparagus	0.71	0.74	0.71	0.78	0.69	0.73	0.74	0.67	0.74	0.7
	Spinach	1.69	1.62	1.56	1.52	1.4	1.48	1.41	1.36	1.35	1.2
	Eggplant	1.69	1.81	1.72	1.81	1.78	1.6	1.66	1.59	1.66	1.44
	Carrot	3.72	3.67	3.41	3.45	3.55	3.62	3.62	3.42	3.49	3.24
	Zucchini	3.52	3.86	3.56	3.92	3.79	3.93	3.95	3.59	3.91	3.48
	Canned	10.25	9.95	10.35	10.18	9.87	10.12	10.08	10.17	10.14	9.9
	Others	9.88	10.28	9.48	9.95	10.04	10.51	10.52	9.84	10.19	9.92
	4th range	3.55	3.6	3.35	3.34	2.96	2.91	2.88	2.87	3.98	4.28

Table 1. (continued)

		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
		kg·inhabitant^{-1}·year^{-1}									
Starch based products	Potato	33.62	33.06	30.65	29.48	30.22	30.7	30.45	29.48	30.33	28.57
	Bread	44.72	40.83	36.32	35.6	35.88	37.26	35.88	35.13	34.67	32.51
	Rice	3.73	3.75	3.86	3.9	4	3.98	3.89	3.85	3.92	3.8
	Pasta	3.71	3.7	3.84	3.78	3.85	4.06	4.02	4.12	4.11	4.08
	Pastries	6.04	5.73	5.68	5.52	5.47	5.86	5.93	6	6.13	5.87
	Biscuits	5	5.02	5.03	5	5.12	5.36	5.39	5.34	5.46	5.22
	Cereals	1.51	1.57	1.58	1.67	1.68	1.67	1.71	1.68	1.71	1.57
Legumes	Chickpeas	1.26	1.22	1.18	1.21	1.21	1.29	1.25	1.25	1.27	1.25
	Beans	1.01	1.02	0.99	0.98	0.97	0.99	0.94	0.9	0.89	0.93
	Lentils	1.03	1	0.98	0.94	0.98	1	0.92	0.89	0.92	0.94
Nuts	Olives	2.39	2.33	2.24	2.24	2.3	2.52	2.56	2.54	2.57	2.52
	Almonds	0.19	0.28	0.25	0.24	0.19	0.23	0.23	0.24	0.21	0.26
	Peanuts	0.25	0.26	0.26	0.26	0.25	0.27	0.25	0.26	0.28	0.28
	Walnut	0.58	0.65	0.62	0.56	0.6	0.6	0.62	0.61	0.65	0.62
	Hazelnut	0.07	0.1	0.14	0.1	0.09	0.09	0.12	0.06	0.05	0.1
	Pistachios	0.13	0.13	0.13	0.12	0.12	0.13	0.12	0.12	0.13	0.13
	Others	1.27	1.24	1.29	1.22	1.21	1.33	1.33	1.36	1.41	1.36
Dairy	Milk	79.96	78.41	76.78	74.51	73.88	74.18	73.32	73.32	72.85	69.91
	Milkshake	2.15	2.27	2.55	2.25	2.25	2.26	2.47	2.62	2.69	2.74
	Yogurt	9.46	9.26	9.81	9.95	9.86	9.8	9.89	9.76	10	9.61
	Butter	0.23	0.24	0.25	0.27	0.3	0.32	0.33	0.31	0.33	0.32
	Cheese	7.74	7.54	7.85	8.03	7.95	8.05	7.77	7.78	8.02	7.66
	Ice-cream	2.09	2.22	2.34	2.39	2.55	2.52	2.77	2.83	2.84	2.96
	Custard	0.92	0.91	0.86	0.88	0.98	1	0.93	0.99	0.9	0.91
Eggs		8.86	8.97	8.26	8.2	8.26	8.63	8.46	8.45	8.57	8.4
Meat	Beef	7.92	7.37	6.75	6.57	6.38	6.19	5.88	5.69	5.62	5.19
	Chicken	14.42	14.18	14.59	14.57	14.77	14.42	14.17	13.79	13.86	13.01
	Lamb	2.65	2.43	2.24	2.08	1.88	1.93	1.79	1.69	1.64	1.5
	Pork	11.76	11.49	11.17	10.74	10.68	10.67	10.74	10.89	10.67	10.22
	Processed meat	13.08	12.4	12.22	12.22	12.44	12.64	11.93	11.73	11.77	11.46

Table 1. (continued)

		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
		kg·inhabitant^{-1}·year^{-1}									
Seafood	Hake	4.29	4.28	4.02	4.09	3.84	3.78	3.5	3.38	3.43	3.15
	Sardine	1.96	1.92	1.75	1.75	1.45	1.67	1.56	1.62	1.62	1.46
	Tuna	0.63	0.58	0.6	0.58	0.66	0.61	0.61	0.62	0.61	0.54
	Trout	0.41	0.36	0.3	0.29	0.32	0.34	0.33	0.32	0.35	0.3
	Sole	1.26	1.2	1.07	0.88	0.78	0.91	0.83	0.72	0.75	0.67
	Cod	0.69	0.82	0.82	0.85	0.88	1.08	1.1	1.02	1.02	1.05
	Mackerel	0.46	0.46	0.4	0.41	0.38	0.43	0.43	0.43	0.43	0.3
	Salmon	0.81	0.8	0.73	0.86	1.09	0.97	1.15	1.39	1.03	1.08
	Sea bass	0.39	0.43	0.41	0.42	0.33	0.4	0.41	0.5	0.55	0.47
	Gilt-head bream	0.95	0.84	0.68	0.59	0.72	0.64	0.61	0.52	0.59	0.55
	Turbot	0.1	0.12	0.08	0.09	0.13	0.1	0.11	0.13	0.11	0.12
	Monkfish	0.55	0.6	0.49	0.46	0.42	0.44	0.41	0.36	0.37	0.36
	Others	4.63	4.4	4.06	3.84	3.86	3.96	3.74	3.46	3.41	3.00
	Clams	0.78	0.74	0.65	0.64	0.67	0.72	0.69	0.64	0.57	0.53
	Mussels	1.46	1.48	1.25	1.23	1.24	1.1	1.21	1.17	1.2	1.2
	Squids	1.88	1.93	1.7	1.47	1.48	1.81	1.61	1.5	1.34	1.23
	Prawns	2.6	2.63	2.28	2.3	2.21	2.09	1.93	1.89	1.87	1.79
	Fish	4.02	4.05	4.09	4.18	4.1	4.25	4.38	4.46	4.52	4.42
	Others	2.27	2.26	1.93	1.84	1.8	1.91	1.79	1.79	1.72	1.5
Ready meals	Preserved	1.38	1.27	1.31	1.38	1.39	1.44	1.42	1.52	1.64	1.69
	Frozen	2.51	2.43	2.46	2.45	2.52	2.6	2.56	2.55	2.52	2.52
	Soup/cream	4.06	3.94	4.27	4.2	4.32	4.29	4.28	4.65	5.02	5.13
	Pizza	1.92	2.01	2.07	2.08	2.07	2.1	2.25	2.29	2.4	2.35
Sweets	Chocolate	3.4	3.4	3.26	3.3	3.45	3.6	3.65	3.72	3.74	3.56
	Honey	0.46	0.42	0.4	0.45	0.41	0.45	0.41	0.41	0.43	0.42
	Sugar	4.25	4.4	4.04	3.97	4.12	4.25	4.34	3.86	3.68	3.46
Oils/fats	Olive oil	9.7	9.75	9.71	9.66	9.26	9.31	9.21	8.37	8.5	7.48
	Sunflower oil	3.59	3.64	3.5	3.35	3.34	3.44	3.17	3.13	3.2	3.73
	Margarine	0.76	0.8	0.82	0.74	0.74	0.77	0.79	0.73	0.72	0.64
Condiments	Ketchup	0.46	0.47	0.48	0.48	0.49	0.51	0.52	0.51	0.48	0.48
	Salt	1.27	1.27	1.29	1.28	1.27	1.36	1.28	1.22	1.19	1.13
	Mayonnaise	1.07	1.1	1.12	1.11	1.14	1.18	1.2	1.19	1.19	1.19
Beverages	Wine	9.26	9.23	9.05	8.86	8.86	9.23	8.93	8.88	9.07	8.52
	Beer	16.76	17.23	16.58	17.1	17.64	17.8	18.18	18.31	18.71	18.51
	Juice	11.66	11.52	12.5	11.73	10.94	10.56	10.23	10.25	9.99	9.21
	Bottled water	55.82	56.08	52.92	51.49	51.58	52.36	52.57	56.48	60.32	61.36
	Soft drinks	45.56	46.06	45.63	46.54	45.9	46.02	45.64	44.68	43.56	41.53
Total		655.57	650.49	627.91	622.3	622.9	631.22	622.79	616.13	621.73	594.31

Table 2. Carbon footprint values for the 104 products included in the Spanish food basket

Food category	Food product	kg $CO_2 \cdot kg^{-1}$	Reference
Fruits	Orange	0.15	(Aguilera et al., 2015a)
	Mandarin	0.15	
	Lemon	0.15	
	Banana	0.3	
	Apple	0.12	
	Pear	0.12	
	Peach	0.12	
	Nectarine	0.12	
	Apricot	0.12	
	Strawberry	0.65	(Clune et al., 2017)
	Melon	0.24	(Aguilera et al., 2015a)
	Watermelon	0.24	
	Green plum	0.12	
	Cherry	0.48	(Clune et al., 2017)
	White grape	0.12	(Aguilera et al., 2015a)
	Kiwi	0.33	(Clune et al., 2017)
	Avocado	0.3	(Aguilera et al., 2015a)
	Pineapple	0.72	(Clune et al., 2017)
Vegetables	Tomato	0.26	(Aguilera et al., 2015b)
	Onion	0.22	
	Garlic	0.24	
	Cabbage	0.24	
	Cucumber	0.33	(Clune et al., 2017)
	Green beans	0.3	(Aguilera et al., 2015b)
	Green pepper	0.23	
	Mushrooms	0.27	(Clune et al., 2017)
	Lettuce	0.24	(Aguilera et al., 2015b)
	Asparagus	0.24	
	Spinach	0.54	(Clune et al., 2017)
	Eggplant	1.35	
	Carrot	0.22	
	Zucchini	0.42	
	4th range salad	0.97	
Starch based foods	Potato	0.24	(Aguilera et al., 2015b)
	White bread	0.67	(Notarnicola et al., 2017)
	Rice	1.66	(Aguilera et al., 2015b)
	Pasta	0.45	(Röös et al., 2011)
	Pastries	2.5	(Werner et al., 2014)
	Wholemeal biscuits	1.3	(Berners-Lee et al., 2012)
	Wholemeal cereals	1	

Table 2. (continued)

Food category	Food product	kg $CO_2 \cdot kg^{-1}$	Reference
Legumes	Chickpeas	0.67	(Clune et al., 2017)
	Beans	0.23	(Aguilera et al., 2015b)
	Lentils	1.03	(Clune et al., 2017)
Nuts	Olives	0.56	(Clune et al., 2017)
	Almonds	0.23	(Volpe et al., 2015)
	Peanuts	0.62	
	Walnuts	0.53	
	Hazelnuts	0.23	
	Pistachios	0.53	
Dairy	Milk	1.23	(Ballús et al., 2014)
	Milkshake	1.23	
	Yogurt	1.5	(González-García et al., 2013a)
	Butter	7.3	(Vergé et al., 2013)
	Cheese	10.14	(González-García et al., 2013b)
	Ice-cream	2.8	(Werner et al., 2014)
	Custard	1.5	(Berners-Lee et al., 2012)
	Eggs	1.8	(Nielsen et al., 2013)
Meat	Beef	28.6	(Clune et al., 2017)
	Chicken	2.5	(González-García et al., 2014)
	Lamb	10.85	(Jones et al., 2014)
	Pork	4.96	(Noya et al., 2017)
	Sausage	3.42	(Noya et al., 2016)
Seafood	Hake	14.55	(Iribarren et al., 2011)
	Sardine	0.36	(Almeida et al., 2015)
	Tuna	1.6	(Hospido et al., 2006)
	Trout	2.75	(Aubin et al., 2009)
	Sole	2.26	(Iribarren et al., 2011)
	Cod	2.16	(Ziegler et al., 2003)
	Mackerel	0.61	(Iribarren et al., 2011)
	Salmon	3.76	(Clune et al., 2017)
	Sea bass	3.55	
	Gilt-head bream	2.26	(Iribarren et al., 2011)
	Turbot	14.51	(Clune et al., 2017)
	Monkfish	9.38	(Iribarren et al., 2011)
	Clam	1.59	(Iribarren et al., 2010)
	Mussel	1.59	
	Squid	3.86	(Iribarren et al., 2011)
	Prawn	14.85	(Clune et al., 2017)

Table 2. (continued)

Food category	Food product	kg $CO_2 \cdot kg^{-1}$	Reference
Canned food	Vegetables	3.7	(Berners-Lee et al., 2012)
	Fruit	1.05	
	Fish	4.15	
Ready meals	Preserved	8.15	(Berners-Lee et al., 2012)
	Frozen	4.15	
	Soups/creams	2.9	
	Pizza	4.15	
Sweets	Chocolate	1.00	(Werner et al., 2014)
	Honey	1.00	(Scarborough et al., 2014)
	Sugar	0.24	(Klenk et al., 2012)
Oils/Fats	Olive oil	1.47	(Pattara et al., 2016)
	Sunflower oil	0.76	(Muñoz et al., 2014)
	Margarine	1.66	(Nilsson et al., 2010)
Sauces	Ketchup	1.6	(Berners-Lee et al., 2012)
	Mayonnaise	1.95	(Hetherington et al., 2012)
Beverages	Wine	0.75	(Berners-Lee et al., 2012)
	Beer	0.45	
	Juice	0.67	(Jungbluth, 2013)
	Soft drinks	0.85	(Berners-Lee et al., 2012)

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Table 3. Consumption frequency (% of inhabitants) of fruits, vegetables, legumes, meat, processed meat, sweets, and soft drinks. The recommended consumption frequency is shown in green.

Fresh fruits					
	Daily	3 times per week	1-2 times per week	<1 time per week	Never/rarely
2006	66.81	14.51	10.47	3.55	4.67
2011	61.43	19.49	10.86	3.71	4.51
2017	64.22	21.36	8.29	3.53	2.60
Vegetables and salads					
	Daily	3 times per week	1-2 times per week	<1 time per week	Never/rarely
2006	40.64	32.6	20.19	3.96	2.61
2011	45.78	34.03	14.41	3.61	2.16
2017	40.42	45.27	10.68	2.21	1.42
Legumes					
	Daily	3 times per week	1-2 times per week	<1 time per week	Never/rarely
2006	3.55	24.43	57.57	10.6	3.84
2011	1.48	23.24	60.17	11.29	3.81
2017	0.83	25.69	61.57	9.92	1.99
Meat					
	Daily	3 times per week	1-2 times per week	<1 time per week	Never/rarely
2006	17.37	54.76	24.67	1.94	1.27
2011	10.55	57.54	28.11	2.46	1.35
2017	9.46	63.01	24.57	1.78	1.18
Processed meat					
	Daily	3 times per week	1-2 times per week	<1 time per week	Never/rarely
2006	20.65	21.92	27.29	16.32	13.82
2011	16.1	22.96	27.89	16.69	16.36
2017	15.53	33.73	28.21	14.18	8.35
Sweets					
	Daily	3 times per week	1-2 times per week	<1 time per week	Never/rarely
2006	36.45	13.76	18.85	14.47	16.48
2011	31.43	16	17.94	15.02	19.62
2017	27.36	24.23	22.90	15.55	9.95
Soft drinks					
	Daily	3 times per week	1-2 times per week	<1 time per week	Never/rarely
2006	17.17	9.21	15.04	14.21	44.36
2011	12.05	9.43	15.95	14.76	47.82
2017	9.13	9.68	17.04	21.30	42.85

SECTION IV

FOOD SUPPLY CHAIN

CHAPTER 9

Environmental footprint of critical agro-export products in the Peruvian hyper-arid coast: a case study for green asparagus and avocado[13]

SUMMARY

Peru has become one of the world's main agricultural hubs for a wide range of fruits and vegetables. Two of these products, avocado and green asparagus, have raised attention in recent years in the international scene due to the high water consumption they require. Consequently, the aim of the current chapter is to perform an environmental assessment of these two products using two life-cycle methods: carbon and water footprint. For the latter, water scarcity, acidification, eco-toxicity and eutrophication impact categories have been selected for assessment. Inventory data were gathered from six different companies located in different regions of the hyper-arid Peruvian coast. The results report that the products are not carbon intensive and are in line with other similar plant-based products. Conversely, the hyper-arid conditions of the cultivation sites require a large volume of groundwater to fulfill de needs of the crops. Interestingly, even though this may lead to overexploitation of groundwater resources in the absence of appropriate management policies, the low mobility of pollutants, namely pesticides, constitutes a natural barrier to protect the degradation of natural water bodies. In conclusion, results from this study may be useful in more concise environmental assessment studies on food products and diets such as those from the previous chapters, considering the consumption of these Peruvian products in many countries in the world. Furthermore, results are also important at regional level since they depict the carbon and water performance of these products and can also be accompanied by cross-cutting certification schemes, including Product Environmental Footprint Category Rules Guidance.

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[13] Esteve-Llorens, X.[b], Ita-Nagy, D.[a], Parodi, E.[a], González-García, S.[b], Moreira, M.T.[b], Feijoo, G.[b], Vázquez-Rowe, I.[a], 2021. Environmental footprint of critical agro-export products in the Peruvian hyper-arid coast: a case study for green asparagus and avocado. (Paper submitted to journal. Ref nº STOTEN-D-21-20578).

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CHAPTER 9 - OUTLINE

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9.1. INTRODUCTION

The Peruvian agricultural sector has become a worldwide reference in recent years due to the great variety of produced and exported agri-food products (Damonte and Boelens, 2019). Although it is a relatively large country, of which approximately 18% is destined for agricultural use (FAO, 2020a), most agro-export products are produced along the hyper-arid Pacific coast (MINAGRI, 2020). Pomegranate, blueberries, rice, cotton, green asparagus, mango, avocado, sugarcane and corn are among the most important products; not only in terms of their consumption in the internal food diet, but also considering the economic profit they generate from exports (INIA/FAO, 2009). In fact, it should be noted that Peru is the world's leading exporter of green asparagus and the third for avocado (SIICEX, 2019). Worldwide consumption of these products has increased considerably in recent years, with predictions indicating that the trend will continue in upcoming years (AGROICA, 2019; MINAGRI, 2019).

The cultivation of agricultural products in coastal Peru is increasingly becoming a threat in terms of water resources availability (Salmoral et al., 2020; Williams and Murray, 2019), considering the hyper-arid climate conditions of the Peruvian coast, where most avocado and asparagus fields are located (PromPerú, 2020). In this region, rainfall is practically absent throughout the year, which means that the supply of water resources arrives entirely from the Andean rivers that trickle into the Pacific Ocean, as well as plentiful groundwater resources along the coastal plains (Salmoral et al., 2020). Unfortunately, the absence of adequate water management strategies has led to an overexploitation of these sources (Banco Mundial, 2017; Schwarz and Mathijs, 2017).

Beyond water depletion implications, there are other important environmental impacts that affect agricultural practices in Peru, such as land use changes (Meyfroidt et al., 2010) or groundwater and soil pollution derived from the intensive use of fertilizers and pesticides (Bergmann et al., 2017). Thus, these pressures may become even more severe if agricultural production continues increasing at the same rate as in recent years, so their quantification and the identification of improvement opportunities is important for stakeholders in the supply chain, especially producers, who are progressively becoming aware of the environmental footprint of their activities. In fact, it should be noted that life-cycle methodologies have been increasingly used in the agricultural sector in Peru to give response to these environmental concerns (Bartl et al., 2012; Vázquez-Rowe et al., 2016).

The use of Life Cycle Assessment (LCA) methodology for the environmental profiling of both dietary patterns (González-García et al., 2018) and food products (Heusala et al., 2020) has been recurrently used in recent years, so it is already widely established for this purpose. Thus, the fact that food consumption patterns depend on a wide range of constantly varying complex supply chain systems is important to understand the environmental profile of all the food products included in human diets in order to carry out the necessary modifications towards more sustainable diets. In fact, one of the strengths of the LCA methodology is its ability to estimate potential environmental impacts in a holistic manner (Hellweg and Milà i Canals, 2014), allowing the identification of environmental hotspots throughout the supply chain and trade-offs between impact categories and environmental areas of protection (ISO, 2006a).

Therefore, the main objective of this chapter is to estimate the environmental impacts linked to the production and export of two widely exported Peruvian agri-food products: green asparagus (*Asparagus officinalis*) and avocado (*Persea americana*). The assessment focused on the two main spheres of interest reported by the local producers: carbon footprint (CF) and water footprint (WF) life-cycle metrics, considering the importance of GHG emissions in food production, but also the high water stress and degradation conditions in the region of interest. As far as the authors were able to ascertain, this research provides the first data and results linked to the CF and WF production of avocado in Peru. In contrast, in the case of green asparagus the study increases the representativeness in terms of cultivated area and number of companies inventoried as compared to a previous study by Vázquez-Rowe et al. (2016). Hence, it is expected that the results for both crops provide insights in terms of corporate decision-making and policy support, as well as an important environmental benchmark for the recipient nations of these products.

This research has been included in the present doctoral thesis attending to several relevant reasons. As abovementioned, food consumption patterns depend on a wide range of constantly varying complex supply chain, so it is very important to understand the environmental profile of all food products included in human dietary patterns to perform the necessary modification towards more sustainable diets. Moreover, in all the chapters of this thesis, bibliographic carbon footprint data have been used for all the foodstuffs that make up the dietary patterns. It is for this reason that it is also very relevant to understand the complex LCA process, while contributing with novel information about strategic products to the literature. Finally, the study was performed in the framework of research stay in the Pontificia Universidad Católica de Perú, supported by Banco Santander through the Santander Iberoamerica Investigación fellowship. In this context, the strategic location of Peru was a key element, taking into account that is one of the world's largest producers and exporters of avocado and green asparagus and considering the growing popularity of these products in the market in recent years.

9.2. Materials and methods

9.2.1. Goal and scope

The main goal of this study was to estimate the environmental footprints, in terms of WF and CF, of the avocado and green asparagus supply chains in the Peruvian coast. The ISO standards specified in ISO 14040 and 14044 were followed to perform the analysis

(ISO, 2006a, 2006b). Furthermore, taking into account that environmental impacts are estimated by calculating WF and CF, the ISO standards specified in ISO 14046 and 14067 were also considered, respectively (ISO, 2019, 2016). The system boundaries in both crops included all the processes related to the productive stages in the field (i.e., soil management, cultivation, fertilization, among others) and post-cultivation processes (i.e., storage, processing and packaging, and transport and storage prior to export at the port of Callao) prior to export. The analysis also included background processes related to the extraction of raw materials, as well as the production of upstream materials used during the production and processing of the two products. The nursery phase was excluded from the system boundaries for both crops due to lack of data. However, prior studies for other crops have suggested that the environmental impacts of the nursery stage are usually negligible (Vázquez-Rowe et al., 2016).

A total of three different agricultural companies were inventoried for each crop. In the case of green asparagus, data for two harvest years (i.e., 2016 and 2017) were reported, whereas in the case of avocado the years ranged between 2017 and 2019. It is important to mention the high representativeness of the data, since large areas of cultivation were considered: approximately 1000 ha of avocado, and about 1,700 ha of green asparagus. The function of the system under study was defined as the delivery of fresh avocado or fresh green asparagus to the harbor of Callao, prior to their export to the international market. Two different functional units (FU) were selected considering the different packaging standards for the studied products: 1 kg of product and 5 kg box of product ready to export for the avocado and green asparagus, respectively. For the former, a unitary weight-based FU was selected given the relatively high variability of packaging formats used for different sizes and destinations. For the latter, the 5 kg box is the most common format for fresh green asparagus and, therefore, was maintained as the unit of reference.

9.2.2. DESCRIPTION OF THE CASE STUDIES

9.2.2.1. AVOCADO

Avocado cultivation is conducted in high planting density of seedlings, with values as high as 833 plants per hectare for certain producers. However, the most common density is 417 plants per hectare. During this stage, different activities such as irrigation, fertilization, application of plant protection agents, are periodically carried out (Salvo et al., 2017). The crops are mostly irrigated with groundwater, although it may be complemented by the endowment of a canal during the rainy season in the Andes. On field irrigation is carried out through a drip irrigation system, which takes the water from the catchment reservoir. The cultivated varieties in the companies inventoried are *Maluma* and *Hass*, which are the most common for export purposes thanks to their regular and abundant production (Schwartz et al., 2016).

The harvesting process is carried out manually, filling the corresponding containers that are then directed to the processing and packaging plant. In the processing line, products are preselected, and a removal of non-desired dirt is carried out through washing and drying processes. Thereafter, avocados are washed and disinfected, sorted, and packed in cardboard boxes. These are palletized and stored in cold rooms, until they are transported by refrigerated trucks (0-5ºC) to the port of Callao, where they are later exported by freight ship to the country of destination (see Figure 9.1).

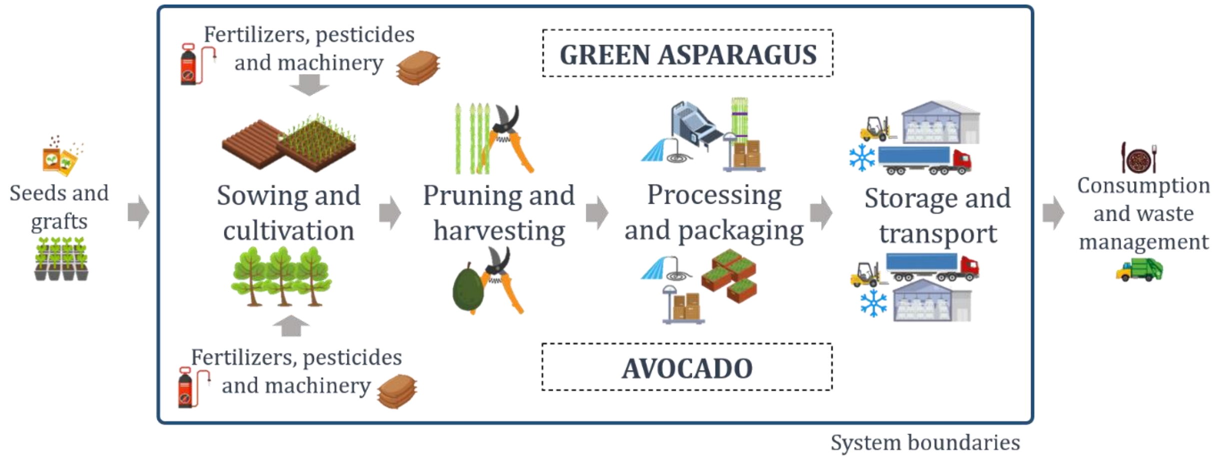

Figure 9.1. Production processes of avocado and green asparagus

9.2.2.2. Green Asparagus

The cultivation and harvesting stages begin with the sowing of the asparagus seeds in a previously conditioned soil (see Figure 9.1). Between 6 to 12 months later, when the seedlings have grown sufficiently, these are transplanted to the final field. The transplanting of the seedlings is carried out to previously conditioned land by means of fallow and the addition of organic matter (i.e., manure, compost, humus etc.). Finally, during the cultivation phase, fertilizers and pesticides are applied, depending on soil conditions and crop requirements (MINAGRI, 2017). After approximately one-year of ripening, the plant is cleared, and the asparagus sprouts are manually harvested as they emerge. This process will be repeated for the upcoming years, in which the plant can yield between one and two harvests per year for approximately a decade.

After being harvested, asparagus are then transferred to the packaging facilities, where they are washed and disinfected in order to remove dirt, pesticides, fertilizers and other undesirable substances (Cillóniz, 2017). Thereafter, they go through a selection and classification process according to the size and thickness of the sprout, they are cut and packaged in polypropylene boxes. Finally, the boxes go through an additional disinfection process and are stored in cold storage until the product is transported by refrigerated truck to Callao, where they are marine- or airfreighted to the main importing markets (i.e., Europe and the US). The temperature at which the fresh green asparagus is transported and distributed (0-5 ºC) is decisive in order to maintain the quality of the products, so it is constantly controlled throughout the transport chain until final distribution.

9.2.3. DATA ACQUISITION AND LIFE CYCLE INVENTORY

Primary data were directly collected from the producing companies (referred to as producers A1, A2 and A3 for avocado, and G1 G2 and G3 for green asparagus) through questionnaires, previously developed by the LCA practitioners (see Table 9.1). Figure 9.2 displays the geographical distribution of all producers involved. The questionnaires detail all the inputs of materials and energy in the different stages of the production system. However, they exclude emissions to the environment, which have been estimated using different methodologies, as described below. In a first stage, the questionnaires were submitted to the appointed person of contact in the agricultural companies for the staff to begin data collection. Thereafter, a validation of the gathered data was carried out during field visits with the company's technical staff. Finally, e-mail exchanges were maintained with the staff from the companies to clarify any pending doubts regarding data interpretation. Thus, primary data include annual values of crop yield, cultivated area, and also operational aspects such as the amount of organic and inorganic fertilizers, plant protection agents (pesticides) and water and electricity use. Additionally, field machinery, cultivation site infrastructure (e.g., irrigation systems), as well as packaging and distribution information, were provided.

Secondary data to cover the gaps during the collection of the primary data and to account for background data were obtained and adapted, if necessary, from the Ecoinvent® v3.4 database (Wernet et al., 2016). For instance, the electricity production mix available for Peru was adapted based on the mix reported by Vázquez-Rowe et al., (2015). Regarding B5 diesel production, its modeling has been carried out according to information from a representative local refinery (Vázquez-Rowe et al., 2019a). In terms of truck transport (16-32 t), Euro 3 emission standards were assumed considering the use of B5 diesel, which is the most common diesel blend in the country. The use of cooling agents in the trucks for cooling was also included within the modelling.

Table 9.1. Average values of *Hass* avocado and green asparagus crops for the period 2016-2019.

		Avocado			**Asparagus**	
	Unit	2016-2017	2017-2018	2018-2019	2016	2017
Cultivation surface	ha	210.0	215.8	118.6	558	558
Production area	ha	141.6	210.0	70.0	558	558
Production yield	t/ha	11	14	7	10	9
Total exports	t	1,468	2,757	1,437	5,951	4,912

Figure 9.2. Map of Peru with the areas where avocado and green asparagus producers involved in the study are located

Emissions were found to be mostly related to the use of fertilizers, plant protection agents, diesel from transport and on-site machinery use. Those related to plant protection agents were estimated using the PestLCI v2 software, which calculates the fraction of pesticide active ingredients that are emitted to air, surface water and groundwater (Dijkman et al., 2012). PestLCI allows using local climate and soil conditions, as well as certain characteristics of the field under study, such as slope, size or tillage method (Vázquez-Rowe et al., 2017c). Regarding the application of fertilizers, these were calculated using different existing methodologies, as shown in Table 9.2 (Vázquez-Rowe et al., 2017a). Finally, combustion emissions from the use of diesel B5 in machinery and other vehicles were calculated using the models described in the EMEP/EEA air pollutant emissions inventory guide (EEA, 2013), and the corresponding emissions were calculated as detailed in Larrea-Gallegos et al. (2017). Emissions linked to tire and brake abrasion, and road dust re-suspension were excluded from the scope of the study considering that no air quality impact categories were included.

Table 9.2**.** Methodologies used for the estimation of air and water emissions from the application of organic and inorganic fertilizers.

Substance	Fertilizer type	Calculation method
Emissions to air		
Ammonia (NH_3)	Inorganic	These emissions depend on the type of chemical fertilizer. Emission factors (% of total N) are as follows: Ammonium nitrate: 2 Calcium nitrate: 2 Urea: 15 Monoammonium phosphate: 2 NPK fertilizers: 2
Dinitrogen monoxide (N_2O)	Organic/Inorganic	The methodology described in the IPCC 2006 standards has been considered (IPCC, 2006). In this standard, a value of 1% of emissions is assigned in relation to the total percentage of N in the fertilizer
Nitrogen oxides (NO_X)	Organic/Inorganic	An emission factor of 2.6% kg NOX/kg N applied has been considered (EEA, 2013).
Carbon dioxide (CO_2)	Inorganic	CO2 emission are considered for urea applications, with the following equation: CO2 kg/ha = 1.57 * urea-N applied kg/ha (Nemecek and Kagi, 2007).
Emissions to water		
Nitrate (NO_3^-)	Inorganic	An emission factor of 30% of the total N applied has been considered (Vázquez-Rowe et al., 2017a).

Tables 1 and 2 of the Appendix detail the inventory data of the cultivation and harvesting stages per FU of harvested avocado and green asparagus, respectively. Regarding the transport of organic fertilizers, average transport distances between 20-100 km have been considered, considering the location of each company and assuming that these inputs will be purchased near the production areas and would be locally manufactured. Transport distances for inorganic fertilizers and plant protection agents are assumed to range from 300 to 800 km, considering that that they are imported through the port in Callao, where most imported goods enter the country. In the case of certain inorganic fertilizers, the modeling has been performed based on the concentration of their active product, which is specified in their technical data sheets.

The data collected for the processing and packaging stages are displayed in Tables 3 and 4 of the Appendix for avocado and green asparagus, respectively. More specifically, data on the electricity used in these processes and the refrigeration of the packaged products, as well as the transport of the products from the cultivation site to the processing plant, are provided. All the data collected in this stage are related to the FU. Regarding the modelling of the transport of avocado and green asparagus from the cultivation sites to their respective processing plants, average distances between 100 and 200 km and Euro 3 vehicles have been considered.

Finally, the transport stage included the freight of the products by road ready to be exported under controlled temperature to the port in Callao (see Tables 5 and 6 of the Appendix). In the same way as the previous stage, a Euro 3 vehicle has been considered, as well as the possible emissions caused by cooling agents. Distances ranging from 200 to 700 km have been considered from the processing plants to the port in Callao.

9.2.4. Allocations and other assumptions

The agricultural companies inventoried cultivate in some cases other crops, such as grapes, blueberries, or pomegranate. Therefore, there are certain energy and material inputs that are shared between the products analyzed and the other mentioned products. In this context, the data collected has been specifically differentiated for the production of avocado and asparagus (e.g., irrigation water, fertilizers and pesticides). Regarding the use of machinery in the cultivation and harvesting processes, only the amount of fuel used in the production of the products under study has been taken into consideration. Similarly, with respect to the use of pumps for well water extraction, only the proportional amount of electricity, based on water consumption, used in these processes has been considered.

a) Avocado

Fresh avocado is the only analyzed product from the companies studied. However, within the processing and packaging of the avocado for export, a small portion of production is destined to the local market due to their size and degree of ripeness. Fresh avocado exports represent, accordingly, about 80% of the total production. Moreover, there is a loss of product during the quality control of the processing stage, representing around 2% of the total production. As abovementioned, environmental impacts associated to planting operations have not been included in the scope of the study, since they can be considered negligible. Likewise, irrigation infrastructure has not been considered due to its long shelf life. Regarding the polypropylene boxes used for the transport of avocado after its harvest, it is estimated that during its shelf life of 15 years they move about 10,000 kg of avocado, so it is expected that their impact per kg of exported avocado is also negligible (Abejón et al., 2020).

b) Green asparagus

The final product analyzed in this study is the packaged fresh green asparagus ready for export. Nevertheless, within processing and preparation of asparagus for export, two marketable products are generated in one of the companies under study. On the one hand, there is fresh green asparagus, which represents ca. 80% of the total exports. On the other hand, the remaining 20% generally corresponds to lower quality asparagus, exported in this case as frozen product. A mass allocation perspective has been applied considering that once processed the system becomes multifunctional, with two final resulting products. The rationale behind this choice is the fact that despite their different market prices, they have similar nutritional content. Moreover, the biophysical partitioning of the two final products is not possible in the early stages of the production system (i.e., cultivation stage).

In relation to the sowing stage, this has been carried out in several years, from 1998 to 2014. Its related environmental impacts have been assigned proportionally considering an estimated length of 12 years of the plantations until a new period of sown. Similarly, irrigation infrastructure has also been considered with the same 12-years life span. In the case of polyethylene boxes used for the transport of green asparagus after harvesting, a lifetime of 15 years has been assumed, to make a proportional allocation.

9.2.5. LIFE CYCLE IMPACT ASSESSMENT

The conversion of material and energy flows into environmental impacts was performed through its processing in the SimaPro 9.0 software (PRé-Product Ecology Consultants, 2017). The computation of the results in the Life Cycle Impact Assessment (LCIA) stage was conducted through the selection of four midpoint assessment methods: Available WAter REmaining – AWARE (Boulay et al., 2018; WULCA, 2020), IMPACT 2002+ (Jolliet et al., 2003), USEtox (Hauschild et al., 2008) and ReCiPe 2016 (Goedkoop et al., 2009). Therefore, the results are reported in terms of emissions causing certain environmental impacts rather than as a potential damage to an area of protection, i.e. endpoint perspective (Huijbregts et al., 2016).

The WF of a product quantifies both water consumption and its degradation, as a consequence of a certain production process. In this sense, water consumption, acidification, eco-toxicity and eutrophication impact categories have been selected (see Table 7 of the Appendix). The selection of analysis methods and impact categories has been derived from a comprehensive evaluation of the different methodologies and recommendations, based on the analysis of a large number of existing methods (EC-JRC, 2011; Hauschild et al., 2012). For the evaluation of the impact related to water consumption, the AWARE method has been selected; it considers the human demand of water resources, measuring the potential water deprivation of an ecosystem. The calculation in this methodology is established based on the direct and indirect water consumption of a production system, and its multiplication by certain characterization factors (Boulay et al., 2018). In this sense, it uses the country's average characterization factor to carry out the relative water consumption. This indicators are limited within a range between 0.1 and 100, where the value of 1 represents the world average and a value of 10 would represent a region in which the availability of water is ten times less than the water available in the world average (WULCA, 2014). In the specific case of Peru, AWARE uses a characterization factor of 24.9 $m^3 \cdot m^{3-1}$ which means that on average in Perú, there is 24.9 times less available water per area, compared to the world average. However, as

Peru is a country with a wide variety of climatic conditions, the characterization factors also vary accordingly, from values of 100 in hyper-arid regions to values of 0.1 in areas with high water availability (e.g., Amazonia). Thus, the results from this study have been obtained for both national and regional (i.e., watershed-based) characterization factors to perform a more accurate analysis.

9.2.6. Statistical analysis

The results reported in this study have been computed individually for each of the three agricultural companies assessed for each product. In addition, we have calculated the weighted mean environmental impacts based on the total annual productivity for each product. Considering the differences in size and maturity of the perennial crops assessed between companies, it was decided that a weighted mean based on total productivity provides a better picture of the environmental impacts rather than providing the arithmetic mean between the companies.

Despite the low number of companies assessed, the total area inventoried is considerable and provides a certain degree of representativeness of the total area of these crops in the country. However, following the criteria described in von Brömssen and Röös (2020) we have not provided inferential statistics for the total population of avocado and green asparagus producers in Peru. Consequently, considering that the aim of this chapter is not to compare the performance between producers, but rather provide a first benchmark for the country, Monte Carlo analysis was not performed for the samples assessed.

9.3. Results and discussion

9.3.1. Environmental profile of avocado

9.3.1.1. Water footprint

The average direct volume of water required for the irrigation in the cultivation sites was on average 10,988, 10,541 and 8,285 $m^3 \cdot ha^{-1} \cdot year^{-1}$ for 2017, 2018 and 2019, respectively. In fact, the direct consumption of water for crop irrigation represents on average ca. 98% of the total consumed water. In contrast, indirect consumption, which represents a small percentage of the total water use, is mainly related to the production of fertilizers and the generation of electricity, which is used mainly to pump water from the aquifers for the irrigation systems. The latter uses important volumes of water given the high reliance on hydroelectricity in the Peruvian electricity mix. The remaining stages included within the processes of cultivation and harvesting (i.e., production of pesticides, use of fuels, irrigation infrastructure and planting) represent less than 1% of the indirect use of water and can be considered as negligible.

When these Life Cycle Inventory values for water use are converted to water scarcity (i.e., AWARE), an average value for the three cultivation sites of 35.9, 33.3 and 19.0 m^3 per

FU is obtained for 2017, 2018 and 2019, respectively, using national characterization factors for irrigation. However, if regionalized specific watershed characterization factors are applied for irrigation, values of 35.3, 19.32 and 68.8 m^3 per FU are obtained for the same years of assessment. In parallel, when the three different production sites are compared within the same year a certain degree of variability is observed, as shown in Table 9.3. However, these variations are more visible when regional specific characterizations factors are applied than when the national average characterization factor is used.

Table 9.3. AWARE results for the avocado crop considering different producers and years of the study.

	2017		2018		2019	
	National factor	Regional factor	National factor	Regional factor	National factor	Regional factor
			Producer A1			
Irrigation	-	-	35.4	83.5	16.7	39.4
Agricultural production	-	-	1.6	1.6	0.5	0.5
Packaging and transport	-	-	0.0	0.0	0.0	0.0
			Producer A2			
Irrigation	38.9	6.1	34.9	5.5	-	-
Agricultural production	0.8	0.8	0.6	0.6	-	-
Packaging and transport	0.0	0.0	0.0	0.0	-	-
			Producer A3			
Irrigation	25.4	109.9	18.4	79.7	19.4	84.0
Agricultural production	0.6	0.6	0.4	0.4	0.5	0.5
Packaging and transport	0.0	0.0	0.0	0.0	0.0	0.0

The reason behind this increased variability when regional watershed-based characterization factors are used is linked to the fact that Peruvian avocado production is located in coastal areas with hyper-arid climate conditions, where the availability of water resources is very limited and must be used as efficiently as possible. It is for this reason that the AWARE method is especially appropriate for the present study, since rather than the use of water depletion as raw indicator of water use, it allows screening the relationship between water availability and withdrawals (Vázquez-Rowe et al., 2017b). It is important to highlight that the impacts related to water consumption are directly proportional to the AWARE characterization factors used for this estimation. In this sense, these values vary significantly between the Peruvian average value (i.e., 24.9 m^3·m$^{3-1}$) and the specific factors for the watersheds in which the water extraction is carried out in the present study (i.e., 4.3 m^3·m$^{3-1}$, 77.4 m^3·m$^{3-1}$ and 58.8 m^3·m$^{3-1}$). Likewise, Peru is a country that must be analyzed with care when using this methodology, since its average value does not represent a value close to a specific area of the country, but rather an arithmetic mean between extreme values from hyper-arid coastal conditions, intermediate condition of water stress from the Andean highlands and the water abundance from the Amazon basin (WULCA, 2014). Therefore, the use of regional characterization factors for irrigation provides more accurate results for the present study. As seen in Figure 9.3a, there is a considerable difference in impact values between using national average and regional characterization factors.

Regarding the categories related to the degradation of water resources, Figure 9.3 shows the weighted average total impacts including the variation between the different producers. For aquatic acidification, an average value of 6.75, 7.23 and 3.40 g of SO_2eq per FU was obtained for 2017, 2018 and 2019, respectively. For these same years, average values of 224.3, 241.7 and 111.46 mg of P eq per FU were computed in terms of aquatic eutrophication impact category. In the case of aquatic eco-toxicity, values of 4003, 2667 and 2267 PAF·m^3·day per FU were obtained for these periods. For all these impact categories, the cultivation and harvesting stage represented between 80% and 90% of the total impacts (see Figure 9.4). Thus, packaging and transport only represented 10-20% of total impacts.

In terms of activities, pollution of water bodies as a consequence of agrochemical emissions, as well as by the production and use of fertilizers and their derived emissions, represent the highest contributions. The contribution of agrochemicals emissions represents 10-30% of the aquatic acidification impacts, while their contribution is very low in the remaining impact categories. In contrast, electricity and diesel use represent a smaller contribution to total impacts in all WF-related impact categories, except for aquatic eco-toxicity, where they represent ca. 10-15% of the impact. In the specific case of aquatic acidification, the production and use of fertilizers suppose on average about 70% for 2017 and about 60% of the total impact for the periods corresponding to 2018 and 2019. These impacts are mainly related to air emissions of ammonia (NH_3) and nitrogen oxides (NO_X) during the application of fertilizers to the crop. The following process that contributes the most to this impact is the emission of agrochemicals (i.e., about 20% in 2017, 30% in 2018 and 15% in 2019) as a result of the application of pesticides to the crops.

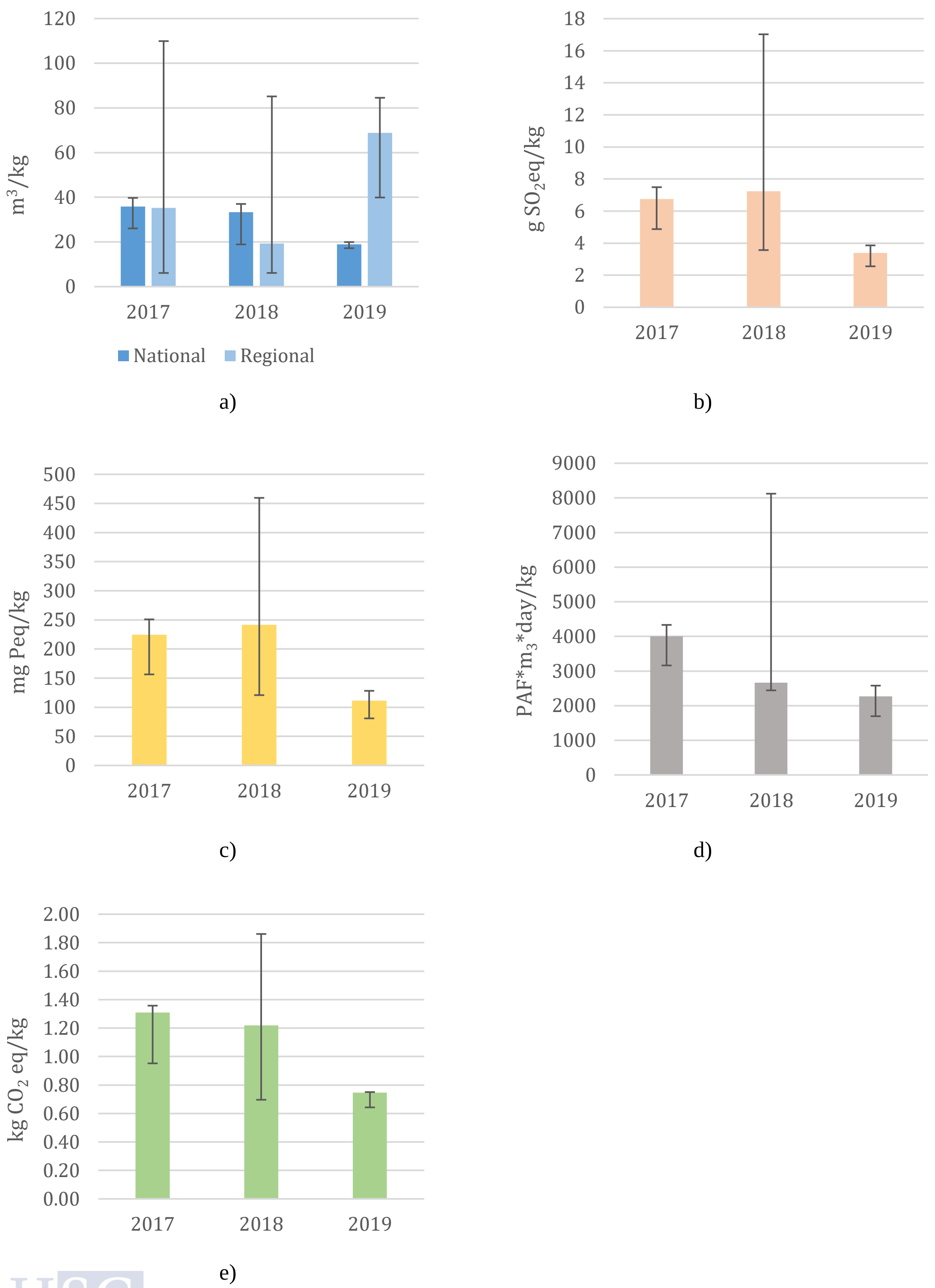

Figure 9.3. Environmental impacts from the production of 1kg of fresh avocado: a) Water scarcity (regional and national characterization factors) b) Aquatic acidification c) Freshwater eutrophication d) Freshwater eco-toxicity e) Carbon footprint. The confidence intervals indicate the variance between the impacts of the different producers.

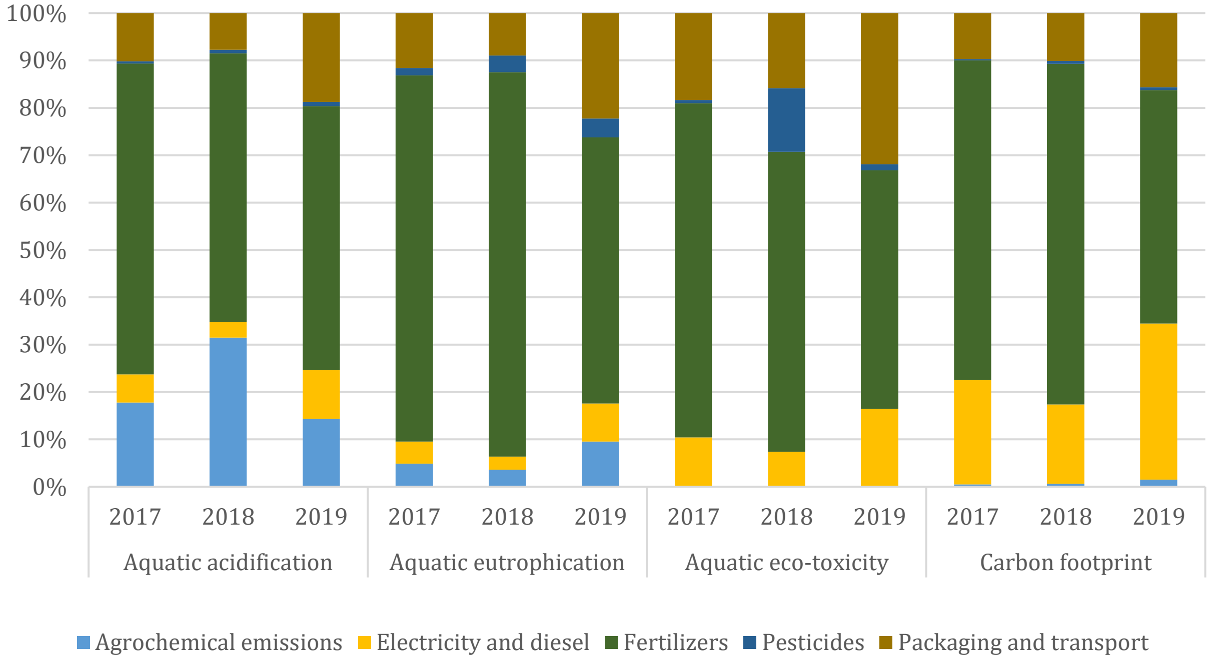

Figure 9.4. Relative contributions of avocado operational activities to selected impact categories.

For eutrophication, the production and use of fertilizers represented on average 60-80% of total impacts in the years assessed, whereas the production of cardboard used in the packaging and transport stage, agrochemical emissions, electricity and diesel, together added up to ~20-30%. In the case of freshwater eco-toxicity impacts, these were mainly linked to the use of fertilizers, with their contribution ranging from about 50% for 2019 to ca. 70% in 2017. To a lesser extent, activities related to the production of packaging materials and energy jointly contributed to roughly 30% of the total impact on average. Interestingly, unlike other conventional agricultural systems, pesticide emissions to freshwater bodies, which are usually the main fraction of eco-toxicity emissions, were very low due to the hyper-arid conditions along the Peruvian coast. More specifically, aridity significantly reduces the mobility of the fraction of pesticides that is not absorbed by the plant or volatilized into the air; thus, it remains on the soil surface without leaching into surrounding water bodies.

9.3.1.2. Carbon footprint

Concerning CF, the production and use of fertilizers is the activity that contributes the most to the total impact representing ca. 70% in 2017 and 2018 and close to 50% in 2019. Nevertheless, energy use (i.e., electricity and diesel) also constitute an important contribution (20-30%), which is mainly linked to the use of electricity for pumping water in the irrigation process. Moreover, about 10% of GHG emissions are associated with packaging and transport activities, while agrochemical emissions and pesticide production can be considered negligible for this impact category. These relative values for the CF can be translated into a total of 1.31 kg CO_2eq per FU in 2017, 1.22 kg CO_2eq in

2018 and the lowest values of 0.75 kg CO_2eq in 2019 (see Figure 9.3e). The difference in GHG emissions per FU between producers is notable especially in 2018 (ranging from 0.70 to 1.86 kg CO_2eq per FU). However, it should be noted that 2018 was the first harvest year for producer A1. Considering that avocado is a perennial tree, it is important to bear in mind that in the first couple of years of production the yield will remain relatively low, to gradually increase towards higher yields with maturity (see Figure 6 in Vázquez-Rowe et al., 2016).

9.3.2. ENVIRONMENTAL PROFILE OF GREEN ASPARAGUS

9.3.2.1. WATER FOOTPRINT

The consumption of water directly for irrigation was, on average, 15,318 $m^3 \cdot ha^{-1} \cdot year^{-1}$ and 15,712 $m^3 \cdot ha^{-1} \cdot year^{-1}$ for 2016 and 2017, respectively. When using AWARE, this direct consumption for irrigation represented almost the entire environmental impact. As shown in Figure 9.5a, there is an important variation between impact values associated with these mentioned characterization factors; while the average impact values associated with the Peruvian national factor are 209.0 $m^3 \cdot kg^{-1}$ and 231.0 $m^3 \cdot kg^{-1}$ for 2016 and 2017, respectively. Average values of 492.8 $m^3 \cdot kg^{-1}$ and 543.9 $m^3 \cdot kg^{-1}$ are obtained for the same years through the regional characterization factor. In parallel, there is also a high variability between producers within the years of cultivation (see Table 9.4), where AWARE results are broken down according to the three producers and the two years of production. Variations between national and regional characterization factors from the AWARE methodology are also considered. However, in contrast to avocado, in which each producer is located in different regions with different characterization factors, green asparagus producers are located in the same watershed and, consequently, have the same associated characterization factor. In this context, cultivation sites are located in the Peruvian hyper-arid coast, so the characterization factor associated with this region for agricultural use (i.e., 79.2 $m^3 \cdot m^{3-1}$) is much higher than the national average one (i.e., 24.9 $m^3 \cdot m^{3-1}$).

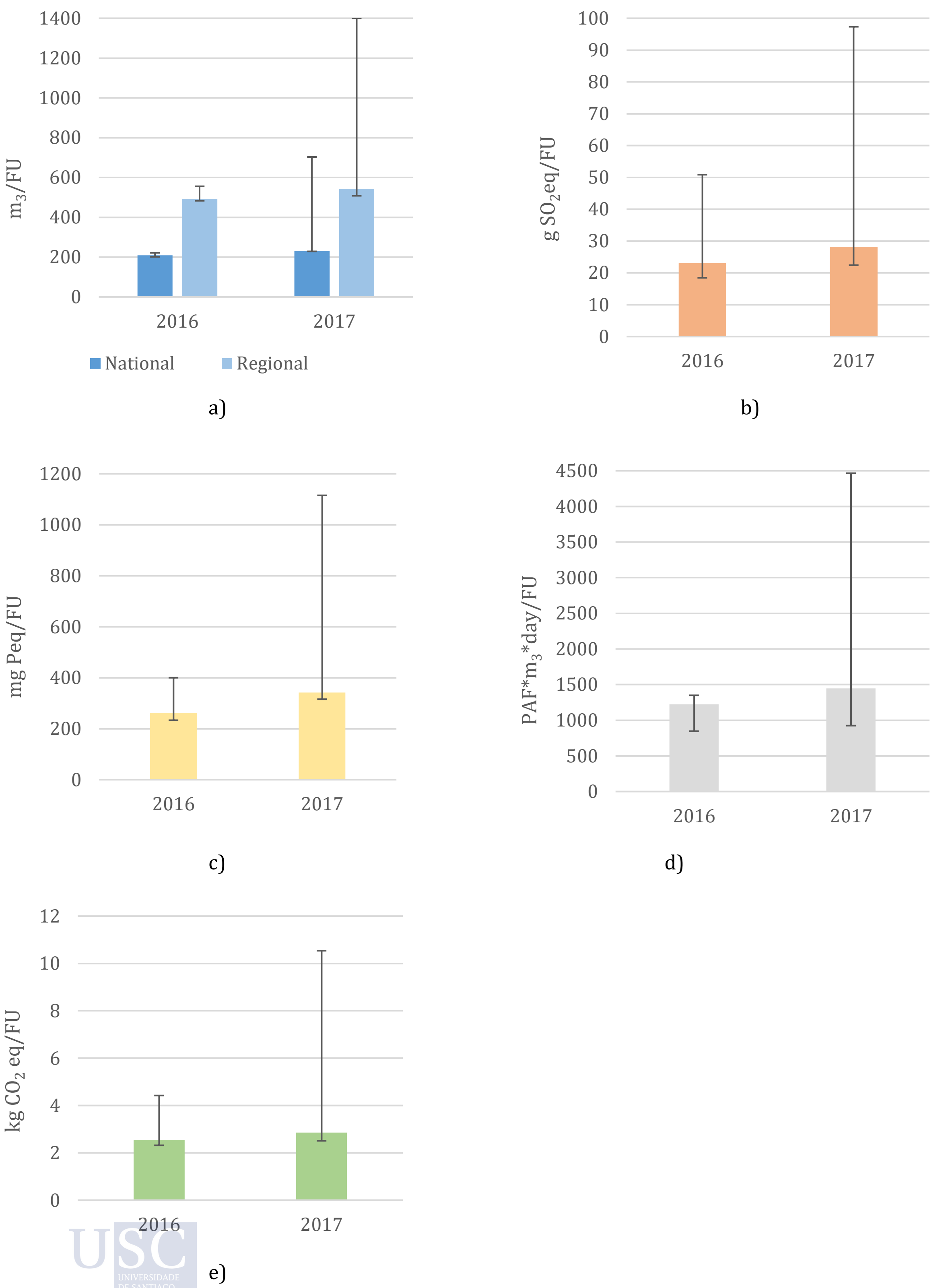

Figure 9.5. Environmental impacts from the production of a 5kg box of green asparagus: a) Water scarcity (regional and national characterization factors) b) Aquatic acidification c) Freshwater eutrophication d) Freshwater eco-toxicity e) Carbon footprint. The confidence intervals indicate the variance between the impacts of the different producers.

Table 9.4. AWARE results for the green asparagus crop considering different producers and years of the study

	2016		**2017**	
	National factor	Regional factor	National factor	Regional factor
Producer G1				
Irrigation	139	443	144	457
Agricultural production	69	32	76	42
Packaging and transport	4.13	3.71	4.19	3.71
Producer G2				
Irrigation	-	-	396	1258
Agricultural production	-	-	298	133
Packaging and transport	-	-	9	9
Producer G3				
Irrigation	167	533	209	664
Agricultural production	46	14	52	15
Packaging and transport	9.05	9.05	9.05	9.05

The indirect use of water for the production of electricity and fertilizers represents the second and third contributions with the greatest impacts. Electricity production represents on average approximately 20% of the total impact for the two years studied and the production of fertilizers about 8% and 14% for 2016 and 2017, respectively. The contributions of the remaining activities included in the cultivation and harvesting stages can be considered as negligible since they represent less than 1% of the total impact. Finally, posing a reduction in the amount of water resource used for irrigation can be considered as a challenge, since the companies are currently operating with technified drip irrigation systems. Despite this, reducing these values would represent a direct reduction of the existing overexploitation of the aquifers, as well as a reduction in the use of energy for pumping water, and a more efficient application of fertilizers and pesticides. In addition, a benefit derived from achieving a more efficient use of water, of especial interest for the companies, could be the first step towards obtaining certification schemes, as discussed in subsection 9.3.4.

Concerning the remaining WF-related categories linked to degradation, Figure 9.5 displays the weighted average total impacts with respect to the variation of the different producers. In this sense, the results for aquatic acidification impact are 23.1 and 28.2 g of SO_2eq per FU for 2016 and 2017, respectively. In the case of aquatic eutrophication, average values of 262 and 342 mg of P eq per FU are obtained respectively for the same periods. Finally, the results for aquatic eco-toxicity impact category are 1,224 and 1,446 PAF·m^3·day per FU for 2016 and 2017, respectively. In this context, the cultivation and harvest stages of green asparagus production represent 60-80% of total impacts (see Figure 9.6), whereas packaging and transport combined represent ca. 30% of the total impact in these categories.

When analyzing this further, it can be observed that most of the impacts can be attributed to the use of fertilizers and their derived emissions (65-80%), in the case of aquatic acidification and eutrophication impact categories; as in avocado cultivation, these impacts are mainly driven by the emission of ammonia (NH_3) and nitrogen dioxides (NO_X) when fertilizers are applied to the crops. Concerning aquatic eco-toxicity impact, the burden is distributed more homogeneously between the use of fertilizers, electricity and diesel and packaging and transport. In the same line as avocado production, and as reported in previous studies conducted along the Peruvian coast for other crops (Vázquez-Rowe et al., 2017b), the extreme aridity of the soil significantly reduces the mobility of the pesticides fraction, mitigating eco-toxic releases to neighboring water bodies.

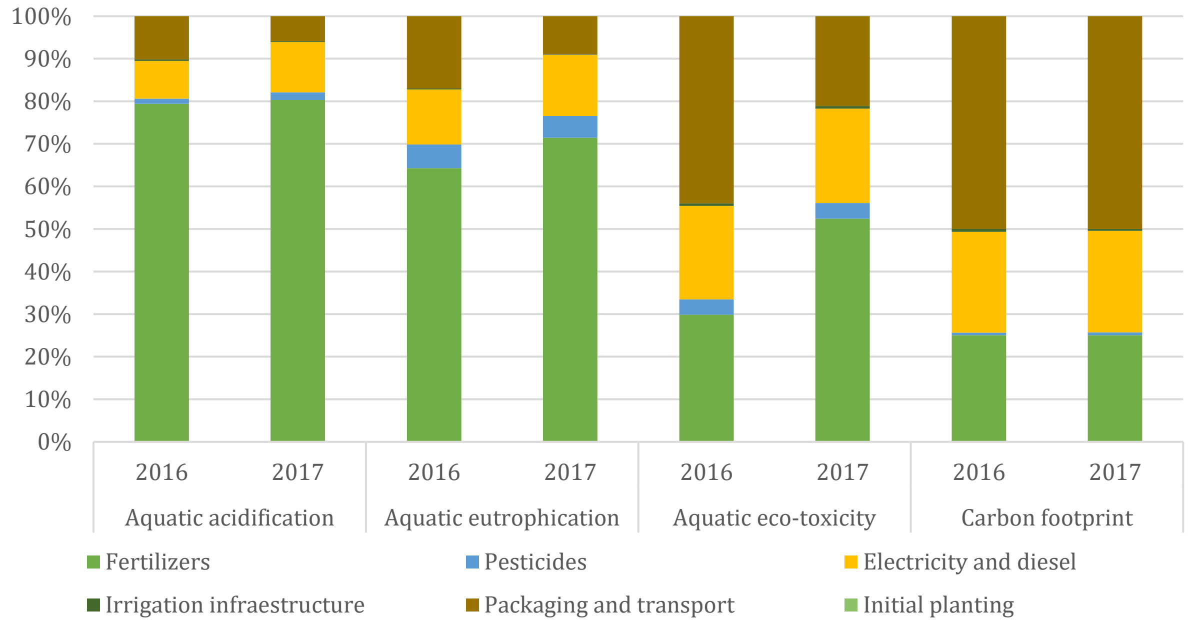

Figure 9.6. Relative contributions of green asparagus operational activities for selected impact categories.

9.3.2.2. CARBON FOOTPRINT

The relative contributions to CF of green asparagus were linked to three main activities: production and use of fertilizers, electricity and diesel and packaging and transport (see Figure 9.6). The contributions of these activities are practically the same in 2016 (about 30% each), while in 2017, fertilizers and electricity and diesel gain importance, approaching 40%. The remaining activities such as initial planting, irrigation infrastructure and the use of pesticides can be considered negligible, as they represent a very low percentage of the total impact. This set of relative contributions is translated into an average CF of 2.54 and 2.85 kg of CO_2 eq per FU for 2016 and 2017, respectively, as displayed in Figure 9.5e. The difference between producers in each year is much larger in 2017 (from 2.54 to 10.54 kg CO_2eq per FU) than in the previous year (from 2.32 to 4.42 kg CO_2 eq per FU). The rationale behind this is that in 2017 producer G2 is included, which was still producing with low yield rates due to the recent planting of the seedlings. As discussed in Vázquez-Rowe et al. (2016), the initial years of harvest are characterized by lower yields and higher environmental impacts per FU.

9.3.3. COMPARISON WITH THE LITERATURE

Avocado and green asparagus have been experiencing an increase in demand in international markets, with a consequent increase in production by the main producing countries to satisfy the consumption needs of importing countries. Thus, the pressure on the environment from these production systems augments and research to evaluate the impact are becoming increasingly necessary to achieve a future sustainable food system. Nevertheless, to date, there are still not many life-cycle studies of these products. In fact, previous studies on these products have mainly limited the scope of their analysis to quantifying GHG emissions (Bartl et al., 2012; Stoessel et al., 2012). To date, only one published article by Vázquez-Rowe et al. (2017c) on the production of *pisco* has evaluated WF in Peru using AWARE and degradative water-related impact categories.

Regarding the production of avocado, Frankowska et al., (2019) performed a study on environmental impacts of fruit consumption in the UK, and obtained considerably higher values for the CF of avocado imported from regions such as Chile and Peru (2.4 kg CO_2 eq·kg^{-1}), than those from this study. However, the rationale behind this is that they include all the stages of the life-cycle, from the production of the avocado to the final disposal of waste at households; thus, taking into account that transport to UK and retailing account for about 40% of the GHG emissions, CF would be approximately 1.44 kg CO_2 eq·kg^{-1}, considering the same stages as those in this study, which is in the upper range of the results obtained in the current study. Stoessel et al. (2012) obtained in this case slightly lower results (≈1.3 kg CO_2 eq·kg^{-1}), considering that the system boundaries include all the stages from its production in Israel until reaching the retailer located in Switzerland. In this case, it is not possible to extract the percentage of GHG emissions associated with transport to Switzerland but considering that these regional freight impacts usually represent 10-15% of total impact, we could assume that these values are highly aligned to those obtained for Peru. Figure 9.7 displays all the mentioned values from the literature in comparison with those from this study.

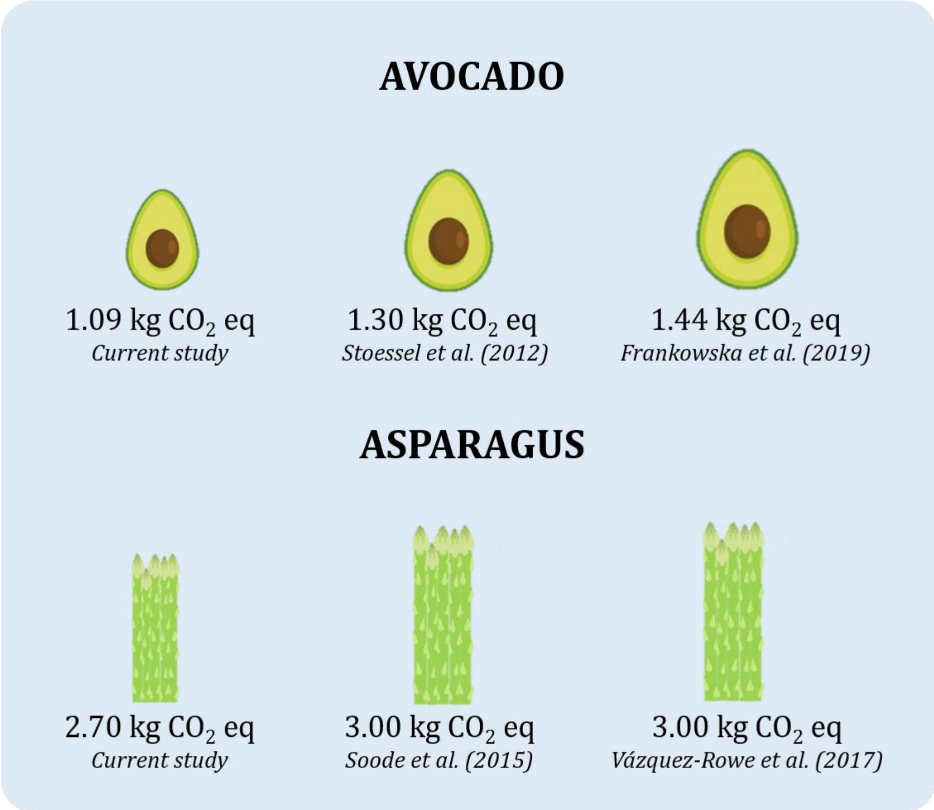

Figure 9.7. Carbon footprint comparison with previous scientific studies for avocado and asparagus production. Results expressed per functional unit.

When focusing on green asparagus, Soode et al., (2015) assessed the CF of its production in Germany. Their results display higher values for the cultivation phase due to the existence of a heating system for the soil in the cultivation site, an additional source of energy use that is not necessary in Peru. Moreover, Vázquez-Rowe et al., (2016) performed its environmental profile in the same region (i.e., Ica) as that of the current study, but using in this case only ReCiPe methodology for the evaluation. In this context, 14 impact categories were selected, including climate change, for which different values for the cultivation stage are obtained depending on the production year and the yield of the cultivation sites. Thus, as the years go by, the trees are more mature and achieve the highest level of yield per unit of land, which also translated into lower environmental impact; for this reason, the CF goes from about 9 kg CO_2 eq per FU in the first year of the study to around 3 kg CO_2 eq. in the last one, four years later. The latter values are in a similar range to those from the current study.

Regarding the remaining impact categories, although the WF of avocado and green asparagus have already been evaluated from a consumptive perspective (i.e., blue, green, and grey WF) in several studies (Mekonnen and Hoekstra, 2011; Novoa et al., 2019; Sommaruga and Eldridge, 2020), it has not yet been assessed from the point of view of water scarcity and pollution. It is for this reason that comparison with other similar studies cannot be made. Therefore, the assessment of WF through the selected impact categories emphasizes the novelty of the present study and gives rise to further research of other regions and different products.

9.3.4. POLICY SUPPORT

The Peruvian coast has become an important regional and worldwide agricultural hub thanks to the high productivity of a wide range of agricultural products, including green asparagus and avocado. This has led Peru's agro-exports to soar since the mid-1990s. However, the hyper-arid coast, where most of this production is concentrated, is making an important hydric effort to supply sufficient water to these crops (Schwarz and Mathijs, 2017), mainly from aquifers. This has led numerous companies to adopt an increasing number of sophisticated irrigation technologies, that have managed to reduce the thirst for water that many of these crops, which are highly water demanding, present.

From a policy perspective, an interesting new initiative is *Certificado Azul*, a national certification scheme that is fostered by the *Autoridad Nacional del Agua* (ANA), which not only seeks transparency and monitoring of water footprinting, but also allows companies to enter a 5-step scheme in which they can implement and validate water saving initiatives. Similarly, the Ministry of the Environment (MINAM) has recently created *Huella de Carbono Perú* (MINAM, 2020), which aims at nudging local companies to report their GHG emissions, although the scheme fosters organizational CF rather than product-based CF analysis. In this sense, with the correct guidance, the agricultural companies assessed in the current study have paved a computational path that could potentially lead them to report their environmental footprints in these national certification schemes. These efforts towards national reporting and transparency must be channeled in such a way that the information gathered can also be of utility for the private and public sector from an international perspective. For instance, considering the importance of the two products analyzed in international trade, these studies could be used as a basis, together with efforts from additional agro-export nations, to generate Product Environmental Footprint Category Rules Guidance (PEFCR).

Peru is the third largest avocado producer in the world and the second largest producer of green asparagus after China. On average, in the period analyzed, Peru produced 500,000 metric tons per year of avocado and ca. 380,000 metric tons annually of green asparagus (FAO, 2020b). Consequently, the GHG emissions released each year can be very relevant. On the one hand, when the average CF for avocado obtained in the current study (i.e., ~1.1 kg $CO_2eq \cdot kg^{-1}$) is extrapolated to national annual production, an estimate of 550,000 t $CO_2eq \cdot year^{-1}$ is obtained. This figure represents roughly 10% of the GHG emissions from Peruvian agriculture sector (FAO, 2020b) and 1% for all national activities (GCP, 2020). On the other hand, when extrapolating the results for green asparagus (i.e., 2.70 kg CO_2eq per FU on average) to the total Peruvian production, the resulting CF is 205,000 t CO_2eq per year, representing roughly 5% of the Peruvian agricultural sector (FAO, 2020b). Although these comparisons should be interpreted with care given the methodological differences that exist between the studies, the relevance of avocado and green asparagus production in the domestic agricultural sector demonstrate that improvements in the management of these crops can have a very powerful effect on reducing national GHG emissions. Unfortunately, it should be noted that, to date, Peruvian nationally-determined contributions (NDCs) in the frame of the Paris Agreement have not included agro-export products within those that deserve specific action, despite their importance at a national but also international level (Vázquez-Rowe et al., 2019b).

It should be noted that practically 100% of green asparagus and a small fraction of the avocado that is exported fresh to Europe has to be sent by airfreight, increasing GHG emissions considerably, as well as other environmental impacts linked to air quality (Stoessel et al., 2012; Vázquez-Rowe et al., 2016). Although international freight has been left beyond the scope of the current study, the high carbon intensity of airfreighting makes it imperative for the Peruvian agro-export industry to diversify the pool of final products that can be exported abroad, including pâtés and other processed products for two main reasons. On the one hand, a reduction in the amount of airfreighted produce that is sent to European and Asian nations is needed, while generating value-added products that may increase the economic benefits. On the other hand, these products, especially avocado, are intensive in the generation of food waste. In this sense, the production of processed avocado products which do not require the freight of the stone (ca. 50% in weight), would avoid unnecessary food miles of inherently wasted parts of the fruit. Nevertheless, as pointed out in recent studies in the Peruvian context, an improvement in local organic waste technologies and management is necessary to lower the GHG emissions that occur in in final disposition (Ziegler-Rodriguez et al., 2019; Vázquez-Rowe et al., 2021). In fact, it should be noted that in the regions analyzed the main disposal sites that are still used are open dumps with no biogas generation management, increasing end-of-life GHG emissions substantially.

9.4. Conclusions

Peru has developed into an important agro-exporting nation thanks to the exploitation of vast groundwater resources along the hyper-arid Pacific coast. Two of the most cultivated products in this geoclimatic area of the country, avocado and green asparagus, also consume important amounts of water per hectare. The results from the current chapter have allowed identifying the main environmental hotspots of these through an environmental footprint using LCA. In line with previous studies on fruits and vegetables, the products assessed did not present high carbon intensity in their cultivation stage. In fact, provided that they are not airfreighted and that the inherent food loss and waste they generate are managed using adequate technologies, their carbon profile appears to be in line with other plant-based products. In contrast, in terms of WF, the results show that important amounts of surface and groundwater are required to fulfil the needs of these perennial crops. Interestingly, although consumption of water may compromise the replenishment of groundwater sources in the area given the lack of robust management policies in terms of water use and expansion of the agricultural frontier, the low mobility of pollutants, namely pesticides, in a hyper-arid environment, constitutes a natural barrier to protect the degradation of natural water bodies.

Additionally, the results presented in this chapter allow covering an important data gap in the environmental assessment literature regarding two products that have been widely discussed given their water demands. Therefore, an important novelty of the study is the potential use of these results in more concise environmental assessment studies on food products and diets, considering the ubiquitous consumption of these Peruvian products throughout the world. In addition, the results also have domestic relevance, as they depict the carbon and water performance of these products. These efforts can also be accompanied by transversal certification schemes, including PEFCRs to foster transparency in terms of the environmental profile of Peruvian agricultural products. While specific improvement actions to mitigate these impacts can be implemented based on the results provided, further studies that evaluate the overall health of coastal aquifers in Peru are necessary to understand the risks linked to declining water levels and their consequences (e.g., increased pumping costs, salinization…).

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Appendix

Table 1. Inventory data of the cultivation and harvest stage per functional unit of avocado.

	Producer A1			
Inputs from technosphere	**Unit**	**2016-2017**	**2017-2018**	**2018-2019**
Irrigation / Water use				
Water use	m^3	-	1.42	0.67
Electricity				
Electricity	kWh	-	0.98	0.77
Fossil fuels				
B5 diesel (machinery)	ml	-	129.7	36.95
Organic fertilizers				
Compost	g	-	-	41.11
Humus	g		-	3.43
ALGAS (Fertimas)	ml		-	0.15
Organic fertilizers transport				
EURO3 16-32 t truck	kgkm	-	35.63	4.50
Inorganic fertilizers				
N-P-K, China	g	-	72.95	-
Urea	g	-	37.67	-
Ammonium nitrate, China	g	-	63.17	18.18
Diammonium phosphate	g	-	1.91	-
Monoammonium phosphate	g	-	6.19	-
Potassium sulfate 50%	g	-	2.71	-
Potassium sulfate 52%	g	-	11.28	-
Potassium phosphate	g	-	3.70	1.34
Potassium nitrate	g	-	41.02	9.32
Phosphoric acid, China	g	-	51.37	5.87
Calcium nitrate, China	g	-	11.81	1.49
Inorganic fertilizers transport				
EURO3 16-32 t truck	kgkm	-	37.72	2.69
Pesticides				
Atrazine	mg	-	1.06	-
Benzimidazole	mg	-	1.70	0.03
Bipyridylium	mg	-	70.85	-
Organophosphorus	mg	-	1,396	334.2
Pesticide	mg	-	220.9	71.92
Pyrethroid	mg	-	1.05	0.21
Thio-carbamate	mg	-	-	66.10
Triazine	mg	-	85.13	11.05
Pesticides transport				
EURO3 16-32 t truck	kgkm	-	2.16	1.38
Outputs to technosphere				
Avocado	kg	-	1.0	1.0

Table 1. (continued)

Producer A2				
Inputs from technosphere	**Unit**	**2016-2017**	**2017-2018**	**2018-2019**
Irrigation / Water use				
Water use	m^3	1.56	1.40	-
Electricity				
Electricity	kWh	0.76	0.29	-
Fossil fuels				
B5 diesel (machinery)	ml	42.80	33.95	-
Organic fertilizers				
Compost	g	-	-	-
Humus	g	-	-	-
Organic fertilizers transport				
EURO3 16-32 t truck	kgkm	-	-	-
Inorganic fertilizers				
Ammonium nitrate, China	g	94.4	94.08	-
Monoammonium phosphate	g	31.17	31.05	-
Potassium sulphate 50%	g	33.74	41.39	-
Phosphoric acid, China	g	9.64	10.35	-
Calcium nitrate, China	g	5.44	6.00	-
Inorganic fertilizers transport				
EURO3 16-32 t truck	kgkm	11.75	12.34	-
Pesticides				
Benzimidazole	mg	23.97	-	-
Pesticide	mg	37.88	17.81	-
Pyrethroid	mg	1.39	1.10	-
Thio-carbamate	mg	173.4	124.2	-
Pesticides transport				
EURO3 16-32 t truck	kgkm	1.89	0.87	-
Outputs to technosphere				
Avocado	kg	1.0	1.0	-

Table 1. (continued)

Producer A3				
Inputs from technosphere	**Unit**	**2016-2017**	**2017-2018**	**2018-2019**
Irrigation / Water use				
Water use	m^3	1.02	0.74	0.78
Electricity				
Electricity	kWh	0.68	0.49	0.52
Fossil fuels				
B5 diesel (machinery)	ml	9.53	6.95	9.08
Organic fertilizers				
Compost	g	-	-	-
Humus	g	-	-	0.27
ALGAS (Fertimas)	ml	-	-	-
Organic fertilizers transport				
EURO3 16-32 t truck	kgkm	-	-	-
Inorganic fertilizers				
Ammonium nitrate, China	g	69.05	48.62	53.59
Potassium sulfate 50%	g	43.12	31.82	33.27
Phosphoric acid, China	g	12.11	8.40	8.40
Inorganic fertilizers transport				
EURO3 16-32 t truck	kgkm	9.76	7.02	7.55
Pesticides				
Benzimidazole	mg	-	-	64.38
Organophosphorus	mg	202.2	147.5	154.2
Pesticide	mg	114.5	204.2	58.21
Pyrethroid	mg	0.31	-	-
Thio-carbamate	mg	-	-	116.4
Triazine	mg	84.80	61.88	64.68
Pesticides transport				
EURO3 16-32 t truck	kgkm	0.24	0.17	0.17
Outputs to technosphere				
Avocado	kg	1.0	1.0	1.0

Table 2. Inventory data of the cultivation and harvest stage per functional unit of harvested green asparagus.

Producer G1			
Inputs from technosphere	**Unit**	**2016**	**2017**
Irrigation / Water use			
Water use	m^3	5.76	5.31
Electricity			
Electricity	kWh	3.23	2.79
Fossil fuels			
B5 diesel (machinery)	g	44.09	34.52
Organic fertilizers			
Humic 15	ml	34.41	18.83
Biofit kit	p	0.24	0.16
Rootchem	ml	1.05	0.55
Supersoil	ml		8.02
Eco Zyme	ml	1.02	0.83
Nutrisorb L	ml	1.99	1.57
CMB fungi	ml	0.01	0.00
Fruit XL	ml	0.10	0.05
Cropfield amino	ml	3.06	1.43
Organic fertilizers transport			
EURO3 16-32 t truck	kgkm	0.84	0.63
Inorganic fertilizers			
Biosil	L	1.24	1.10
Potassium chloride, as K_2O	g	57.35	66.25
Sodium borate	g	10.75	9.41
Phosphate fertilizer, as P_2O_5	g	21.86	58.58
Ammonium nitrate, as N	g	31.54	36.96
Calcium nitrate	g	57.35	73.22
Magnesium sulphate	g	32.62	50.21
Potassium sulfate, as K_2O	g	60.93	73.22
Zinc sulfate	g	10.04	10.46
Urea, as N	g	10.04	11.51
Fertichem Fe	ml	620.1	467.2
Fertigro 8-24-0	g	2.42	1.645
Klingquel mix	mg	530.5	139.5
Calcium oxide	mg	258.1	251.1
Inorganic fertilizers transport			
EURO3 16-32 t truck	tkm	10.39	13.60
Outputs to technosphere			
Green asparagus	kg	5.00	5.00

Table 2. (continued)

Producer G2			
Inputs from technosphere	**Unit**	**2016**	**2017**
Irrigation / Water use			
Water use	m^3	-	12.67
Electricity			
Electricity	kWh	-	11.64
Fossil fuels			
B5 diesel (machinery)	g	-	68.18
Inorganic fertilizers			
Urea, as N	g	-	209.1
Ammonium nitrate, as N	g	-	536.4
Phosphoric acid	g	-	200.0
Potassium chloride, as K_2O	g	-	9.09
Potassium sulfate, as K_2O	g	-	327.3
Calcium nitrate	g	-	190.9
Magnesium sulphate	g	-	236.4
Boric acid	g	-	18.18
Zinc sulfate	g	-	18.18
Inorganic fertilizers transport			
EURO3 16-32 t truck	kgkm	-	556.4
Outputs to technosphere			
Green asparagus	t	-	5.5

Table 2. (continued)

Producer G3			
Inputs from technosphere	**Unit**	**2016**	**2017**
Irrigation / Water use			
Water use	m^3	1.10	1.38
Electricity			0.00
Electricity	kWh	0.44	0.54
Fossil fuels			0.00
B5 diesel (machinery)	kg	6.94	8.54
Organic fertilizers			0.00
Humic acid	L	-	4.15
Organic fertilizers transport			0.00
EURO3 16-32 t truck	tkm	-	0.77
Inorganic fertilizers			0.00
Urea	g	308.1	408.1
Urfos	g	289.7	233.9
Potassium chloride	g	367.8	490.8
Calcium nitrate	g	147.2	197.7
Magnesium sulphate	g	173.4	198.5
Boric acid	g	25.94	41.92
Zinc sulfate	g	14.06	16.15
Citric acid	mg	-	226.2
Phosphoric acid	mg	-	1.15
Aminovits 48	L	-	475.4
Aminovits calcium – boron	ml	-	369.3
Brotone	ml	-	38.46
Cropfield traslock BM	ml	-	256.9
Ekotron 15 liquid	ml	-	28.85
Fetrilon combi I	mg	-	3.08
Latigazo Fe	ml	-	313.5
Latigazo Mg	ml	-	313.5
Microelements HS	ml	-	335.8
Nutri potasio plus 38%	ml	-	94.62
Ultraferro	mg	-	3.85
Urea	mg	-	2627
Stopit	ml	-	110.0
Inorganic fertilizers transport			
EURO3 16-32 t truck	kgkm	394.4	507.7
Outputs to technosphere			
Green asparagus	kg	5.00	5.00

Table 3. Inventory data of the processing and packaging stage per functional unit of avocado for all the years and producers of the study.

	Unit	**All years**
Inputs from technosphere		
Materials		
EURO3 16-32 t refrigerated truck	kgkm	210
Water use*	kg	-
Electricity*	kWh	-
Wood (pallet)	g	12.31
Cardboard	g	85.06
Metal band	g	0.42
Staples	g	0.06
Fresh avocado	kg	1
Outputs to technosphere		
Fresh avocado	kg	1

* No reported values by the processing plant. They are assumed to be very low and will not affect the total computation of inputs and outputs.

Table 4. Inventory data of the processing and packaging stage per functional unit of green asparagus

	Unit	2016	2017
Produce G1			
Inputs from technosphere			
Materials			
Polypropylene	g	210	210
EURO3 16-32 t refrigerated truck	kgkm	636	636
Water use	kg	17.1	20.2
Electricity	kWh	0.63	0.65
Fresh asparagus	kg	5	5
Outputs to technosphere			
Green asparagus box	p	1	1
Producer G2			
Inputs from technosphere			
Materials			
Polypropylene	g	210	210
EURO3 16-32 t refrigerated truck	kgkm	118	118
Electricity	kWh	0.08	0.08
Fresh asparagus	kg	5	5
Outputs to technosphere			
Green asparagus box	p	1	1
Producer G3			
Inputs from technosphere			
Materials			
Polypropylene	g	210	210
EURO3 16-32 t refrigerated truck	kgkm	17.5	17.5
Electricity	kWh	0.08	0.08
Fresh asparagus	kg	5	5
Outputs to technosphere			
Green asparagus box	p	1	1

Table 5. Inventory data of the transport to the port of Callao per functional unit of avocado for all the years of the study.

	Unit	All years
Producer A1		
Inputs from technosphere		
Materials		
EURO3 16-32 t refrigerated truck	kgkm	650
Outputs to technosphere		
Fresh avocado	kg	1
Producer A2		
Inputs from technosphere		
Materials		
EURO3 16-32 t refrigerated truck	kgkm	704
Outputs to technosphere		
Fresh avocado	kg	1
Producer A3		
Inputs from technosphere		
Materials		
EURO3 16-32 t refrigerated truck	kgkm	70.2
Outputs to technosphere		
Fresh avocado	kg	1

Table 6. Inventory data of the transport stage per functional unit of green asparagus.

	Unit	2016	2017
Producer G1			
Inputs from technosphere			
Materials			
EURO3 16-32 t refrigerated truck	kgkm	1,120	1,120
Fresh asparagus box	p	1	1
Outputs to technosphere			
Green asparagus box	p	1	1
Producer G2			
Inputs from technosphere			
Materials			
EURO3 16-32 t refrigerated truck	kgkm	1,890	1,890
Fresh asparagus box	p	1	1
Outputs to technosphere			
Green asparagus box	p	1	1
Producer G3			
Inputs from technosphere			
Materials			
EURO3 16-32 t refrigerated truck	kgkm	1,900	1,900
Fresh asparagus box	p	1	1
Outputs to technosphere			
Green asparagus box	p	1	1

Table 7. List of impact categories included in the water footprint of the avocado and green asparagus

Assessment method	Impact category	Category type	Unit
AWARE	Water consumption	Consumptive	$m^{3}\cdot m^{3-1}$
IMPACT 2002+	Acidification	Degrading	kg SO_2 eq
ReCiPe 2016	Eutrophication	Degrading	kg Peq
USEtox	Eco-toxicity	Degrading	PAF*m^3*day

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SECTION V

CONCLUSIONS

CHAPTER 10. GENERAL FINDINGS AND CONCLUSIONS OF THE THESIS

The main goal of this doctoral thesis was to assess the sustainability of different dietary patterns, from a multi-criteria perspective, taking into account both environmental and nutritional factors, as well as socioeconomic aspects. Moreover, the environmental impacts of the food production chain were also evaluated from a life cycle approach through two case studies of relevant agricultural systems in current dietary patterns as they are the avocado and green asparagus. This topic is in line with the growing concern about the mitigation of climate change and achieving healthier food consumption patterns that are environmentally friendly and accessible to the entire present and future population. In this regard, current dietary patterns are characterized by a huge deviation from traditional recommendations, due to a high consumption of animal-origin and ultra-processed products, and sweets. These foods are responsible for a large number of severe food-related chronic diseases, as well as for the majority of greenhouse gases (GHG) emissions derived from the food supply chain. It is for this reason that changing current food consumption patterns towards healthier ones based mainly on the intake of plant-based products is one of the most powerful tools to combat climate change, along with other cornerstones such as technological improvements or the reduction of food loss and waste. At the same time, the achievement of these diets also represents a great opportunity to improve global food security and quality, as they would ensure adequate nutrition and prevent millions of cases of malnourishment, food-related diseases and premature deaths. In this context, the methodologies on environmental and nutritional impact analysis applied in this thesis have been proved as useful for this purpose, also in combination with other complementary instruments for the integration of socioeconomic aspects. The main findings and conclusions extracted from Sections II, Section III, and Section IV are listed below.

Section II: The Atlantic diet. The main objective of the section is to estimate both the environmental impact and the nutritional quality, through the carbon footprint (CF) and different nutritional quality indexes, respectively, of the traditional recommendations of the Atlantic diet, which is considered an example of a healthy diet. In addition, this section aims at comparing these values with those from current food consumption patterns of the area where the Atlantic diet is located, such as northwestern Spain and northern Portugal. In this context, the recommended Atlantic diet is studied in Chapter 3, and current food consumption patterns from Galicia and northern Portugal are evaluated in Chapter 4 and Chapter 5, respectively. The main outcomes from these chapters are detailed below.

Chapter 3 studies the traditional dietary pattern of the Atlantic diet, taking into account the environmental impact, specifically the CF, and also the nutritional profile through the Nutrient Rich Diet 9.3 index. For this purpose, a weekly menu is designed according to the amount and proportions of food groups recommended by the health authorities. In this regard, the results showed that the Atlantic diet can be considered beneficial both from the point of view of the environmental impact and the nutritional quality. In this sense, the high consumption of plant-based products and moderate consumption of seafood gives it an advantage over other dietary patterns richer in consumption of livestock products. In terms of contributions to CF, the stage of food production is the main responsible for GHG emissions. Followed by cooking and transport stages, respectively. Moreover, meat, dairy and seafood products, especially beef and cheese, have the highest individual footprints although the consumed amount of these products (in grams) is much lower than other foodstuffs such as vegetables and fruits, considered as basic central foods in the traditional Atlantic diet. Additionally, it has also been found, that the higher percentage of animal protein in the diet, the greater CF associated with it, so as a conclusion, it can also be said that a lower intake of animal protein is directly related to a more sustainable diet from an environmental point of view. In this sense, the total CF of the diet could be reduced by minimizing the intake of livestock products. Thus, even though the ingested quantities of meat and dairy products are not very high in the Atlantic pattern, they could still be reduced, being compensated by the intake of plant-based proteins. However, the increase in the nutritional quality together with the improvement of the CF associated to the shift of proteins intake from animal to vegetable-origin needs to be analyzed in more detail.

Chapter 4 continues with the study of the Atlantic diet, but in this case, with the current consumption patterns associated to one of the traditional locations of this diet: Galicia (northwest Spain). In this case, menus are not designed as in Chapter 3, but for the estimation of the CF and the nutritional quality, data are taken from food consumption surveys obtained directly from the population. Accordingly, the main results prove that there is currently a significant deviation between food consumption patterns and the recommendations of the Atlantic diet from an environmental and nutritional point of view. It is for this reason that Galician dietary pattern obtains a higher CF and lower nutritional quality so a change in these towards achieving a higher degree of adherence to the recommendations would be beneficial. The consumption of processed and pre-cooked foods can be considered as main hotspot of the Galician diet together with an excessive consumption of livestock products so that leaving aside and reducing the consumption of these foods respectively would help significantly to reduce the CF and to increase the nutritional quality of the diet. In this sense, it would be beneficial to take advantage of what was mentioned in Chapter 3 and reduce the consumption of animal protein and replace it with plant-based protein such as legumes. These outcomes can be useful for regional sanitary authorities and policy makers to directly act on the weakness that are responsible of the greatest loss of nutritional density and increased CF.

As last part of the Section II, Chapter 5 focuses on the study of food consumption in northern Portugal, which is another region where the Atlantic diet is traditionally located, also coexisting with the Mediterranean diet. In this case, the purpose of the study, in addition to evaluate the CF and the nutritional quality in 2008-2016 period, is to propose the necessary modifications in the Portuguese food consumption pattern to achieve a more sustainable dietary pattern both from an environmental and nutritional point of view. The outcomes shown that on average for all the years of the period, the CF of the food consumption pattern is considerably higher in comparison with those from recommendations (i.e., Atlantic and Mediterranean diets), but otherwise, it is a similar to figures from other current food consumption patterns. The reason for this high CF is mainly the high consumption of energy and livestock products. The variation of CF over the period studied is relatively stable over the years, with only a slightly decrease in the middle years of the period, and it is related to a decrease in the consumption of meat, dairy, seafood, and fats. At the same time, the nutritional quality showed an opposite trend, since it is in the middle years of the period where the highest scores are reported, due to a lower intake of harmful elements such as sodium, saturated fats, and sugars, which are directly related to the ingestion of dairy products, fats, and sweets. Thus, considering that the average CF of the Portuguese diet is too high, and the nutritional quality can be significantly improved, several modifications in quantity and proportions of foods consumed are proposed in order to achieve a more sustainable consumption pattern. Accordingly, the recommendations from EAT-Lancet commission for a planetary health diet are followed to make these modifications and reduce the quantities of certain products such as meat, dairy and fats, and replacing them by others healthier and more environmentally friendly such as fruits, vegetables, legumes, and nuts. The effects of these affordable modifications are clearly reflected in the environmental and nutritional impacts of the dietary pattern, as the CF is reduced by approximately 25% and nutritional quality is increased by 67%. Measures like these are necessary to achieve healthier and more environmentally friendly food consumption patterns both in Portugal and in other regions where decision-makers can make a difference and help consumers through social campaigns, marketing, education strategies, to provide them a clearer picture of what should be included in their food basket.

Section III: Spanish dietary habits. This section is focused on the study of different Spanish dietary patterns, from a multicriteria point of view, including environmental and nutritional profiles of the food consumption patterns, and other variables such as socioeconomic aspects, climatic conditions, and efficiency scores. Accordingly, three different studies are carried out including Chapter 6, Chapter 7 and Chapter 8, and these are detailed below.

The premise underlying Chapter 6 is that food consumption habits can vary considerably, depending on several aspects (e.g., culture, lifestyle, geography), even within the same country. In this context, the Spanish food consumption patterns are assessed, considering the related GHG emissions and nutritional adequacy of consumption data from household's food surveys. For this purpose, the country is divided into five different climatic zones (i.e., Oceanic, Continental, Mediterranean, Continental with Mediterranean influences and Subtropical), according to the average temperatures and rainfall throughout the year. CF and nutritional adequacy of the food consumption patterns differ depending on the zone. Accordingly, colder regions located in the north of the country are related to an increase in CF mainly because of a higher consumption of livestock products and energy intake. However, these zones also obtain a better nutritional adequacy due to a more balanced diet that includes a higher consumption of fruits, vegetables, seafood and olive oil compared to the rest of the areas. Attending to the consumption of livestock products, it would be interesting to develop new policies aimed at reducing their consumption, while promoting moderate ingestion of those of higher quality produced under a more sustainable way. Differences in dietary habits and their corresponding CF according to the climatic zones detected in the present study can be useful as first step for the study of the relationship between food consumption patterns and the environmental conditions of the region. Additionally, given the urgent need to achieve more sustainable consumption patterns as an effective measure for the mitigation of climate change, specific regional policies, such as nutrition and environmental education, should be needed to improve food choices in supermarkets, including within the same country.

Chapter 7 analyzes the efficiency of dietary habits of the 17 autonomous regions of Spain, from a multi-criteria point of view, and taking into account environmental (i.e., CF), nutritional (i.e., Nutrient Rich Diet 9.3 index), and socioeconomic aspects (i.e., number of deaths due to tumors of the digestive system, obesity-related health expenditure, and number of persons with food shortages). This novel methodological framework involves the use of Data Envelopment Analysis (DEA) for the efficiency assessment of dietary patterns, including the aforementioned variables, and considering each autonomous regions as a Decision Making unit (DMU). Seven regions have been identified with the most suitable dietary patterns according to the selected sustainability criteria, and the remaining ones (except for Asturias (<0.60)) obtained multi-criteria efficiency scores above 0.60. These results show the presence of relatively good dietary habits in Spain, that could be related to the influence of traditional dietary patterns such as the Mediterranean and de Atlantic diet. The coupled use of DEA within the methodological framework proposed in this work proved to be feasible and valuable for the sustainability efficiency assessment of dietary habits. It is for this reason that beyond the case study of Spain, the proposed methodology could contribute to define sound guidelines and policies based on the performance of regions with efficient (i.e., sustainable) food consumption patterns.

Chapter 8 studies the relationship between the CF of the average Spanish food consumption pattern and socioeconomic factors over a ten-year period (i.e., 2008-2017), including the economic crisis of the past decade. Therefore, this research is based on the influence of external factors on eating habits as well as the pressure that these habits exert on the environment. CF shows a generalized decrease over the years, but according to the main findings, this is not always synonymous with a healthier diet, since although the consumption of animal-origin products decreases over the years, it also does that of some essential foods for a healthy and balanced dietary pattern such as fruits, vegetables or olive oil; contrarily, there is also an increase of the ingestion of precooked meals, and processed foodstuffs, which also is directly related to a significant decrease in the nutritional density of a diet. This trend moves food habits away from traditional recommendations, which can be more pronounced for the most vulnerable population groups with an increase of the poverty risk rate and the difficulty of accessing to healthy food. Otherwise, it also can be deciphered from the results that the Spanish population is still far from being aware of the environmental impacts derived from food, considering the large number of animal-origin products that are still part of the dietary pattern today.

Section IV: Food supply chain. The main goal of this section is to assess in detail the environmental impacts that the production of foods that make up dietary pattern can exert over the environment, considering two highly popular foodstuffs such as avocado and green asparagus as case studies. Furthermore, this research has been included in the thesis owing to several relevant reasons such as the importance of understanding the complexity of Life Cycle Assessment process and all the processes involved within the food supply chain. Having said this, Chapter 9 analyzes from a Life Cycle Assessment perspective the CF and water footprint (WF) of two of the most cultivated products in the hyper-arid Peruvian coast such as avocado and green asparagus. The outcomes from this chapter have allowed to identify the main environmental hotspots throughout the production process of these foods, allowing to conclude that in line with previous studies on fruits and vegetables, the products assessed do not present high carbon intensity in their cultivation stage. Nevertheless, when focusing on WF, it can be concluded that important amounts of surface and groundwater are required to fulfil the needs of these perennial crops, also considering that rainfall is practically non-existent throughout the year. Interestingly, although consumption of water may compromise the replenishment of groundwater sources in the area given the lack of robust management policies in terms of water use and expansion of the agricultural frontier, the low mobility of pollutants, namely pesticides, in a hyper-arid environment, constitutes a natural barrier to protect the degradation of natural water bodies. Furthermore, the main outcomes of this study allow to cover an important data gap in the environmental assessment literature regarding two products that have been widely discussed given their water demands. Another important novelty of the present research is the potential use of these results in more concise environmental assessment studies on food products and diets, considering the ubiquitous consumption of these Peruvian products throughout the world.

LIST OF PUBLICATIONS

Scientific papers

Xavier Esteve-Llorens; Carmela Darriba; Maria Teresa Moreira; Gumersindo Feijoo; Sara González-García. "Towards an environmentally sustainable and healthy Atlantic dietary pattern: Life cycle carbon footprint and nutritional quality". Science of the Total Environment. 2019, Vol. 646, 704. Impact factor in 2019: 6.55; Q1. ISSN: 0048-9697 **Chapter 3** is based on this publication. The author of this publication contributed to the conceptualization process, obtaining the results, writing the manuscript and in the subsequent review and publication process.

Towards an environmentally sustainable and healthy Atlantic dietary pattern: Life cycle carbon footprint and nutritional quality

Author: Xavier Esteve-Llorens,Carmela Darriba,Maria Teresa Moreira,Gumersindo Feijoo,Sara González-García

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Xavier Esteve-Llorens; Maria Teresa Moreira; Gumersindo Feijoo; Sara González-García. "Linking environmental sustainability and nutritional quality of the Atlantic diet recommendations and real consumption habits in Galicia (NW Spain)". Science of the Total Environment. 2019, Vol. 683, 71. Impact factor in 2019: 6.55; Q1. ISSN: 0048-9697. **Chapter 4** is based on this publication. The author of this publication contributed to the conceptualization process, obtaining the results, writing the manuscript and in the subsequent review and publication process.

Linking environmental sustainability and nutritional quality of the Atlantic diet recommendations and real consumption habits in Galicia (NW Spain)

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Xavier Esteve-Llorens, Ana Cláudia Dias, Maria Teresa Moreira, Gumersindo Feijoo, Sara González-García. “Evaluating the Portuguese diet in the pursuit of a lower carbon and healthier consumption pattern”. Climatic Change. 2020, Vol. 162, 2397. Impact factor in 2020: 4.13; Q1. ISSN. 1573-1480 **Chapter 5** is based on this publication. The author of this publication contributed to the conceptualization process, obtaining the results, writing the manuscript and in the subsequent review and publication process.

SPRINGER NATURE

Evaluating the Portuguese diet in the pursuit of a lower carbon and healthier consumption pattern

Author: Xavier Esteve-Llorens et al
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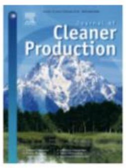
Xavier Esteve-Llorens, Corné Van Dooren; Milena Álvarez, Maria Teresa Moreira; Gumersindo Feijoo; Sara González-García. “Environmental and nutritional profile of food consumption patterns in the different climatic zones of Spain”. Journal of Cleaner Production. 2020, Vol. 279, 123580. Impact factor in 2020: 7.24; Q1. ISSN: 0959-6526. **Chapter 6** is based on this publication. The author of this publication contributed to the conceptualization process, obtaining the results, writing the manuscript and in the subsequent review and publication process.



Environmental and nutritional profile of food consumption patterns in the different climatic zones of Spain

Author: Xavier Esteve-Llorens,Corné Van Dooren,Milena Álvarez,Maria Teresa Moreira,Gumersindo Feijoo,Sara González-García
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Efficiency assessment of diets in the Spanish regions: A multi-criteria cross-cutting approach

Author:
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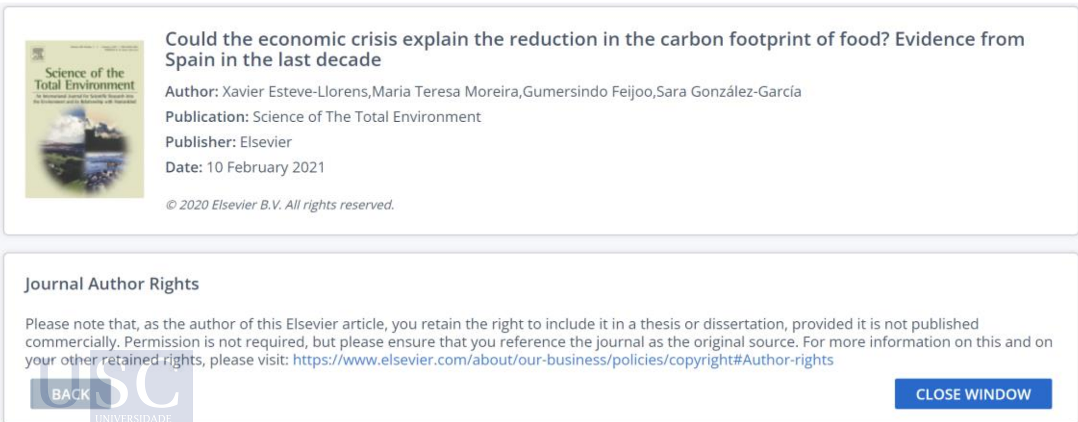
Could the economic crisis explain the reduction in the carbon footprint of food? Evidence from Spain in the last decade

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