TRansition paths to sUstainable legume-based systems in Europe

TRUE Deliverable 5.1 (D29), Report, Public

Report on Life Cycle Assessment Methodology for Assessing the Environmental Sustainability of Legume Value Chains

Last updated: 25 April 2018

Compiled by: David Styles (Bangor University)

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

Deliverable Description & Contributors

- **Due date:** 31th March 2018
- **Actual submission date:** 25th April 2018
- **Project start date:** 1st April 2017
- **Duration:** 48 months
- **Work package:** Environment (WP5)
- **Work package leader:** Mike Williams (TCD, IE)
- **Deliverable Title:** Life cycle assessment for legume value chains
- **Nature of deliverable:** Report
- **Dissemination level:** PU: Public

- **Deliverable description:** This report, **'Report on Life Cycle Assessment Methodology for Assessing the Environmental Sustainability of Legume Value Chains'**, presents the overarching approach and specific methodological details planned for the environmental assessment of legume value chains in accordance with the objectives of Work Package 5 of the TRUE project. Particular emphasis is placed on functional units, system boundaries and impact categories to be considered in life cycle assessment, and interaction with economic modelling and nutritional assessment being undertaken in other TRUE project work packages.

- **Contributors:**

  - David Styles, Bangor University, (**BU**), UK;
  - Maggie March, Scotland Rural Collage (**SRUC**), UK;
  - Sabhdh Sheeran,(**TCD**), IE;
  - Mike Williams, Trinity College Dublin, (**TCD**), IE;

Content

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

1. Background to the TRUE Project

1.1 TRUE Project Executive Summary *(abbreviated)*

TRUE's perspective is that the scientific knowledge, capacities and societal desire for legume supported systems exist, but that practical co-innovation to realise transition paths have yet to be achieved. TRUE presents 9 Work Packages (WPs), supported by an *Intercontinental Scientific Advisory Board*. Collectively, these elements present a strategic and gender balanced work plan through which the role of legumes in determining '*three pillars of sustainability*' – '*environment*', '*economics*' and '*society*', may be best resolved.

TRUE realises a - multi-actor approach, the basis for which are three *Regional Clusters* managed by WP1 ('*Knowledge Exchange and Communication*', University of Hohenheim, Germany), that span the main pedo-climatic regions of Europe, designated here as: *Continental*, *Mediterranean* and *Atlantic,* and facilitates the alignment of stakeholders' knowledge across a suite of 24 Case Studies. The Case Studies are managed by partners within WPs 2-4 comprising '*Case Studies*' (incorporating the project database and *Data Management Plan*), '*Nutrition and Product Development*', and '*Markets and Consumers*'. These are led by the Agricultural University of Athens (Greece), Universidade Catolica Portuguesa (Portugal) and the Institute for Food Studies and Agro Industrial Development (Denmark), respectively. This combination of reflective dialogue (WP1), and novel legume-based approaches (WP2-4) will supply hitherto unparalleled datasets for the '*sustainability WPs*', WPs 5-7 for '*Environment*', '*Economics*' and '*Policy and Governance*'. These are led respectively by greenhouse gas specialists at Trinity College Dublin (Ireland; in close partnership with Life Cycle Assessment specialists at Bangor University, UK), Scotland's Rural College (in close partnership with University of Hohenheim), and the Environmental and Social Science Research Group (Hungary), in association with Coventry University, UK). These *Pillar WPs* use progressive statistical, mathematical and policy modelling approaches to characterise current legume supported systems and identify those management strategies which may achieve sustainable states.

A key feature is that TRUE will identify key *Sustainable Development Indicators* (SDIs) for legume-supported systems, and SDI thresholds (or 'safe limits') consistent with sustainable states. Data from the *foundation WPs* (1-4), shared between the *Pillar WPs* (5-7), will be resolved by WP8, '*Transition Design*', using machine-learning approaches (*e.g. Knowledge Discovery in Databases*), allied with *DEX* (*Decision Expert*) methodology to enable the mapping of existing knowledge and experiences. Co-ordination is managed by a team of highly experienced senior staff and project managers based in The Agroecology Group, a Sub-group of Ecological Sciences within The James Hutton Institute. Further information is available via the project webpage: https://www.true-project.eu/

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

1.2 Work Package Structure

The flow of information among TRUE WPs displayed in Figure 1. This current report is part of WP5 on the Environmental consequences of legume production and consumption, which will generate environmental indicators of legume sustainability that will complement economic indicators generated in WP6, and feed in to policy (WP7) and overall assessment (WP8) objectives. WP5 will rely on data provided by project partners and project Case Studies, in addition to literature review and data mining undertaken within the WP.

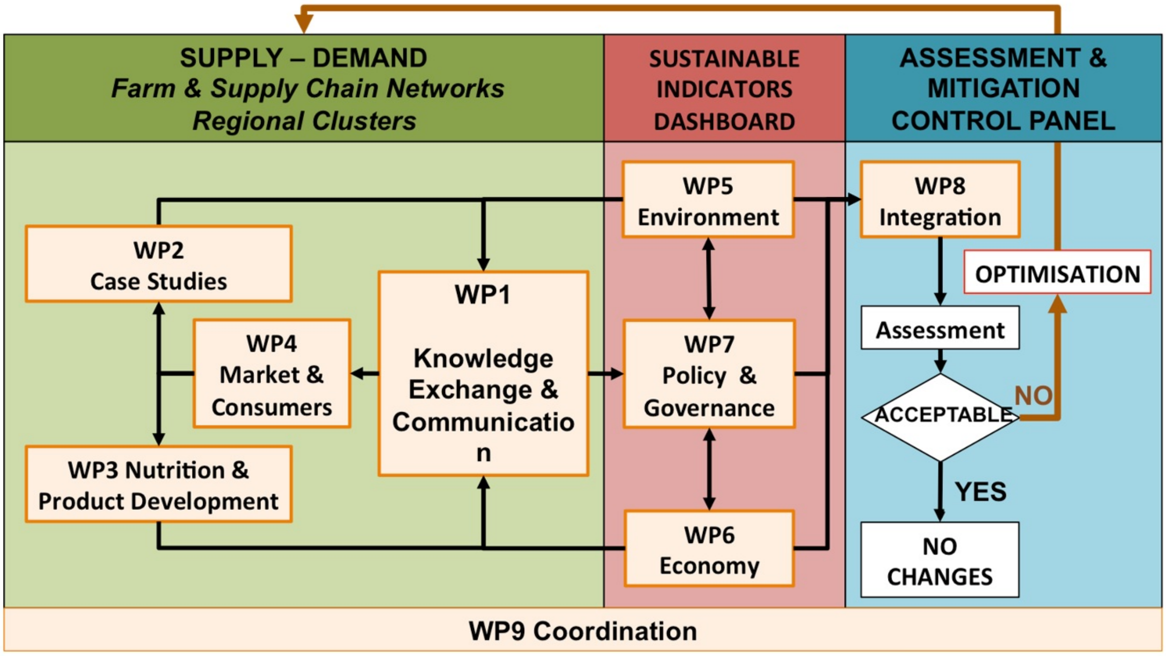

Figure 1. *Flow of information and knowledge in TRUE, from definition of the 24 Case Studies (left), quantification of sustainability (centre) and synthesis and decision support (right).*

1.3 TRUE Objectives (abbreviated)

Overall TRUE project objectives are listed below.

Objective 1: Facilitate knowledge exchange (UHOH, WP1)

- *Develop a blue-print for co-production of knowledge*

Objective 2: Identify factors that contribute to successful transitions (AUA, WP2)

- *Relevant and meaningful Sustainable Development Indicators (SDIs)*

Objective 3: Develop novel food and non-food uses (UCP, WP3)

- *Develop appropriate food and feed products for regions/cropping systems*

Objective 4: Investigate international markets and trade (IFAU, WP4)

- *Publish guidelines of legume consumption for employment and economic growth*
- *EU infrastructure-map for processing and trading*

Objective 5: Inventory data on environmental intensity of production (TCD, WP5)

- Life Cycle Analyses (LCA) -novel legumes rotations and diet change

Objective 6: Economic performance - different cropping systems (SRUC and UHOH, WP6)

- *Accounting yield and price risks of legume-based cropping systems*

Objective 7: Enable policies, legislation and regulatory systems (ESSRG, WP7)

- *EU-policy linkages (on nutrition) to inform product development/uptake*

Objective 8: Develop decision support tools: growers to policy makers (JSI, WP8)

- *User friendly decision support tools to harmonise sustainability pillars*

1.4 Work Package 5 (Environment) objectives

The aim of this WP is to provide a coordinated life cycle based assessment (LCA) of the environmental impact of legume production and processing coupled with a nutri-economic analysis of legume-enriched diets for feed and food. This work package will answer the following overarching questions.

- What is the environmental footprint of animal feed and food produced from legumes, considering nutrient cycling and break-crop effects in legume-rotations across major EU agro-climatic zones?
- What are the optimum legume-enriched diets/food choices for improving health, that decrease the environmental footprint – including indirect effects incurred during supply chain transitions - and reduce direct costs to the consumer?

The specific objectives of this WP are as follows.

1. Produce a practical report outlining the LCA methodology to be used in TRUE (*this report*).
2. Assess using attributional LCA the environmental footprints of legume products, and benchmark against conventional alternatives.
3. Assess a range of European diets in terms of environmental burden and nutrient quality. By constructing a suitable nutrient density functional unit for the attributional LCA, food choices will be scored according to both decreasing environmental impact and increasing health.
4. Assess how increasing the proportion of legumes and legume products in a range of European diets may increase the beneficial nutrient content of diet/food choice but decrease their environmental impact, accounting for rotation and land use effects associated with supply chain transitions.
5. Calculate the combined environmental, health and purchase costs of diet/food choices, and assess if increasing the proportion of legumes and legume products in these may increase the affordability and environmental sustainability of healthier diets.

1.5 Purpose of this LCA Methodology Report

This LCA Methodology Report is the first deliverable from WP5, and addresses Objective 1 (above). The purpose of this report is to describe the analytical framework for both the attributional and consequential LCA studies that will be undertaken as part of the TRUE project. The report will outline the methodological approach in terms of scenarios to be analysed, data sets to be used, and LCA methods to be applied.

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

1.6 Context for environmental assessment of legumes

Globally, “sustainable intensification” of agriculture, to deliver more output from less input, is imperative if projected demand for food is to be met from a finite land area, minimising further encroachment onto areas of high nature value and terrestrial carbon (C) storage (Godfray et al., 2010). Major challenges to the sustainability and resilience of EU food production include: (i) dependence on resource use including energy, water, fertilisers, animal feed and food; (ii) low nutrient use efficiency (NUE) and associated nutrient pollution; (iii) high levels of greenhouse gas emissions; (iv) soil degradation. In developed countries, food consumption contributes between 15 to 28% to overall GHG emissions (Garnett, 2011). Agriculture requires large quantities of water and inorganic fertilisers, accounting for the majority of water withdrawals from groundwater, rivers and lakes (Jagerskog et al., 2012), causing dramatic disruption to global N and P cycles leading to pollution of groundwater, aquatic ecosystems and marine fisheries (Diaz et al., 2008), and is a dominant cause of biodiversity loss (Foley et al., 2011). Across the EU, high dependence on synthetic nitrogen (N) fertiliser (SNF) and overall NUE of just 20% lead to annual leaching losses of 3 Tg, NH_3-N emissions of 2.8 Tg and N_2O emissions of 0.37 Tg (Godfray et al., 2010).

Legumes offer a form of ecological intensification that can address many of these challenges. Legume cropping has resource and environmental advantages over non-legume cereal and forage systems, including lower fertiliser usage, higher NUE, lower GHG emissions, improved soil quality, and possibly enhanced biodiversity of favourable organisms (Table 1) (Jensen and Hauggard-Neilsen, 2003; Muňoz et al., 2010; Jensen et al., 2011).

Table 1. *Environmental aspects of legume cropping, adapted from Jensen and Hauggard-Neilsen, (2003).*

	Positive Aspects	Negative Aspects
N_2 Fixation and Reduced Fertiliser Usage	Decreased GHG emissions Decreased fossil energy use Increased soil C and N assimilation Increased soil N uptake	Soil acidification
Legume Crops: Cropping/ Pre-Cropping	Decreased GHG emissions Decreased ammonia volatilisation Decreased N leaching Increased soil N uptake	N losses from green manure/cover crop/residue incorporation
Legume Crops: Post-Harvest and Long-Term	Increased N-benefit to following crop Increased soil fertility Increased C sequestration Increased above/below ground biodiversity	N losses particularly in intensive systems

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

In terms of N_2O, emissions from N-fertilised pastures may be more than 8 times higher than those from grass/clover swards, while emissions from N-fertilised crops maybe more than 3 times higher than those from grain legumes (Jensen et al., 2011). Although the use of legumes in agriculture may reduce reliance on SNF, NUE may remain relatively low where legumes are used as a cover crop for mulching or green manure. In such cases, N_2O fluxes may equal those from conventional crops (Baggs et al., 2000; Gomes et al., 2009), accompanied by significant leaching of N to groundwater (Beaudoin et al., 2005; Campiglia et al., 2011; Jensen et al., 2011). Increasing NUE may be possible by incorporating cereal straw with the high N legume residues and thus trapping the N for longer within the soil (Frimpong et al., 2011). WP5 will mine data and liaise with WP2 partners on legume Case Studies to match the most appropriate emission factors to cropping regimes across major EU agro-climatic zones, feeding in to LCA of legume and conventional crop cultivation.

A significant share of the environmental footprint of EU food consumption arises outside of the EU (PBL, 2011), *via* "teleconnections" in global commodity markets. Soybean meal is a high quality animal feed associated with high yields and high feed conversion efficiency, which can enhance the apparent efficiency of milk and meat production (Jønker et al., 2002; Havlik et al., 2014). However, the upstream ecosystem damage caused by soybean can be high owing to indirect land use change (ILUC) (Morton et al., 2006). Annually, the EU imports around 14 Mt of soya, largely from South America, a hotspot for biodiversity and terrestrial C loss from agricultural expansion (Morton et al., 2006; Lüscher et al., 2014). This makes the EU vulnerable to future soya availability constraints, particularly given the projected growth of soya imports to China. Indigenous protein feed sources including forage legumes, faba beans, peas and lentils are an effective substitute for imported soybean (Smith et al., 2015). The mitigation opportunity represented by imported-soya substitution will be evaluated in WP5.

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

2. Life Cycle Assessment Methodology

2.1 Attributional LCA

Attributional LCA is a vital tool to evaluate the environmental intensity and resource efficiency of food value chains, accounting for environmental burdens (*e.g.* GHG emissions) and resource use at all stages from production through distribution to consumption and disposal. The basic framework is an iterative procedure involving: (i) system boundary definition; (ii) data collection to quantify relevant inputs and outputs (energy, raw materials, co-products, waste, emissions); (iii) characterisation of inputs and outputs in relation to specific environmental impacts; and (iv), interpretation (Finkbeiner et al., 2006). This WP will combine statistical data-mining of published literature with data from past[1], and present EU-funded projects and other partner projects[2], and from LCA databases (*e.g.* Ecoinvent v.3), to undertake an attributional LCA of forage and grain legume cropping in grassland and arable rotations representative of major EU agro-climatic zones. To this core analysis will be added LCA building blocks for legume processing specific to three production pathways highlighted from TRUE project Case Studies, namely:

- legumes for animal feed;
- legumes for fish feed; and,
- legumes for human consumption.

2.1.1 Scope and functional units

The primary purpose of the attributional LCA is to quantify the environmental intensity of legume products, expressed as food footprints, for comparison against "conventional" food products that may be substituted by European-grown legumes, especially animal-based protein foods or imported animal feeds (Figure 2). Products to be foot-printed will include clover/grass pasture, faba bean, common bean, pea and soybean.

[1] LEGUME FUTURES http://www.legumefutures.de/; EUROLEGUME http://www.eurolegume.eu/; LEGATO http://www.legato-fp7.eu/

[2] *E.g.* CLEANER COWS http://www.nrn-lcee.ac.uk/cleaner-cows/

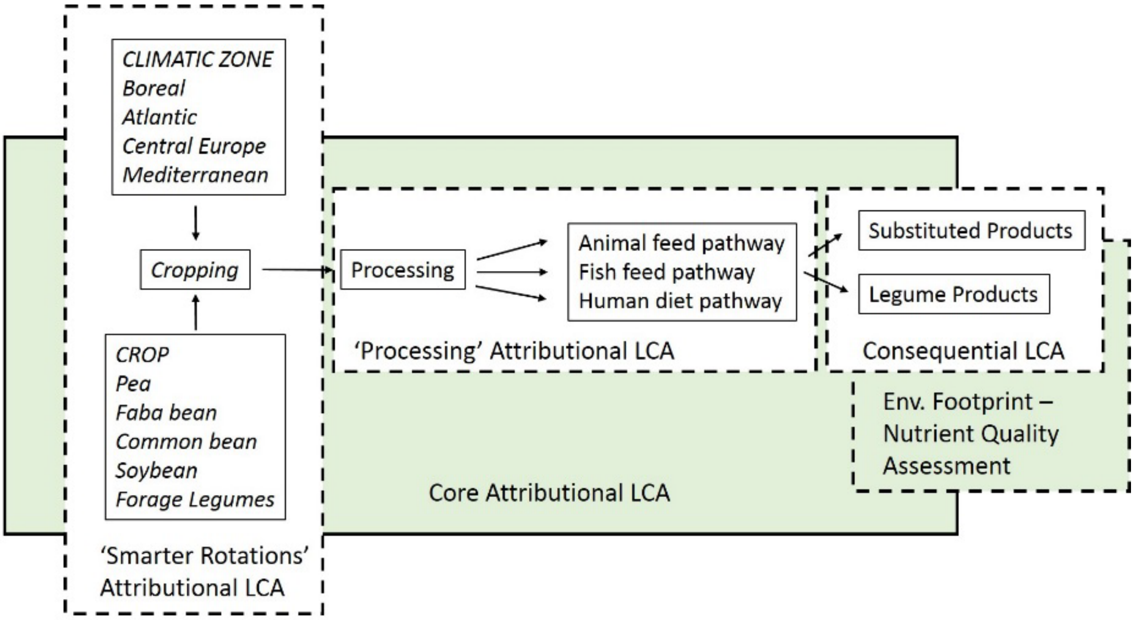

Figure 2. *Boundaries for attributional LCA of legume product chains, indicating expansion of boundaries to calculate wider environmental consequences of product substitutions via consequential LCA.*

Multiple functional units will be considered for food/feed footprints will be applied, depending on the specific purpose of the study question being answered (see WP5 objectives):

- kg feed/food product (basic data presentation);
- kg protein (to compare alternative protein-rich food/feeds);
- MJ metabolisable energy (to compare alternative energy-dense food/feeds); and,
- nutritional quality unit (*e.g.* Aresanault et al., 2012) (to compare foods as key nutritional components of diet in nutri-environmental footprints – elaborated in section 2.4).

Where possible, systems will be entirely separated for LCA, as *per* ISO recommendations (Finkbeiner et al., 2006). However, where multiple co-products are derived from a single crop, shared processes (*e.g.* during cultivation) will be allocated based on the respective energy flows in the co-products as a default allocation methodology. Sensitivity analyses will be performed by also employing an economic allocation method.
Significant SNF substitution has been reported for legume-cereal rotations (Godfray et al., 2010) and for grass-clover swards (Nyfeler et al., 2009). LCA boundaries will be expanded to evaluate full legume- and baseline- rotation cycles as *per* Kopke and Nemecek (2010) – elaborated in next section on consequential LCA. Break crop and enhanced N cycling effects will be considered in full rotations within the consequential LCA framework (section 2.2), but will also be accounted for within an attributional LCA framework as environmental "credits" and allocated co-products, respectively. This will generate novel, more accurate environmental footprints for legume crops that will be expressed alongside footprints derived from more conventional energy- and economic-based allocation.

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

2.1.2 Environmental impacts

Environmental footprints will be expressed using JRC (2012) methodology for global warming (CO_2 eq.), eutrophication (N eq.), acidifying gas emissions (primarily NH_3) (mmol eq.), fossil resource depletion (MJ eq.) and water footprint (Hoeskstra, 2016).

2.1.3 Inventory compilation

Inventory compilation will be based on activity and yield data for cultivation and processing from a wide range of sources, including TRUE Case Studies, statistics on fertiliser application and yields of representative rotations in each agro-climatic zone (Euostat, FAO Stat, national statistics such as Defra 2011 RB209 fertiliser manual in the UK), unit process data (Ecoinvent v.3) and legume yield and emission factors from past and present projects. Data required for nutri-environmental assessment in relation to diet choice are detailed in section 2.4. In order to benchmark environmental footprints for legume products against substituted food products, data mining will be undertaken, supplemented by additional LCA where necessary, to compile environmental footprints for major sources of imported EU legumes, animal-protein and cereal starch products.

A basic database will be generated for important legume processes and legume crop/product footprints, and will be made publicly available via TRUE project dissemination. Data quality and parameter uncertainty will be recorded in the database, and used to inform subsequent uncertainty analyses in attributional and consequential LCA. This work will also provide the building blocks for subsequent consequential LCA of human and animal diet scenarios.

2.1.4 Interpretation

Results will be presented in both conventional (allocated product footprints) and novel (*e.g.* credit-adjusted footprints) formats, with detailed contribution breakdowns to facilitate interrogation and interpretation. Scenarios will cover a range of plausible cropping parameters (sensitivity analyses). Uncertainty will be quantified by inputting uncertainty ranges for important but uncertain variables, in order to evaluate aggregate uncertainty in results, *e.g.* using Monte Carlo and/or error propagation methods. Peer review will be sought for all results to be made public, undertaken through the journal review process for published results and invited review by independent academics with expertise in food footprints.

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

2.2 Consequential LCA

2.2.1 Goal and scope definition

Consequential LCA evaluates environmental loading changes associated with management and policy interventions, accounting for indirect effects incurred *via* market signals (Schmidt, 2008; Styles et al., 2017). WP5 will apply consequential LCA to evaluate the net global environmental benefits associated with transitions towards legume-modified diets that include direct substitution of meat and dairy proteins and also the inclusion of EU-grown legumes in animal product supply chains.

Consequential LCA will be applied in order to extrapolate the potential environmental benefits of increased legume production and consumption at the EU scale, considering diet change and substitution of animal protein and soya imported to the EU (Figure 3), for a series of diet change scenarios shaped by policy (WP7), value chain innovation (WP4), and macro-economic modelling (WP6), as indicated in Figure 4.

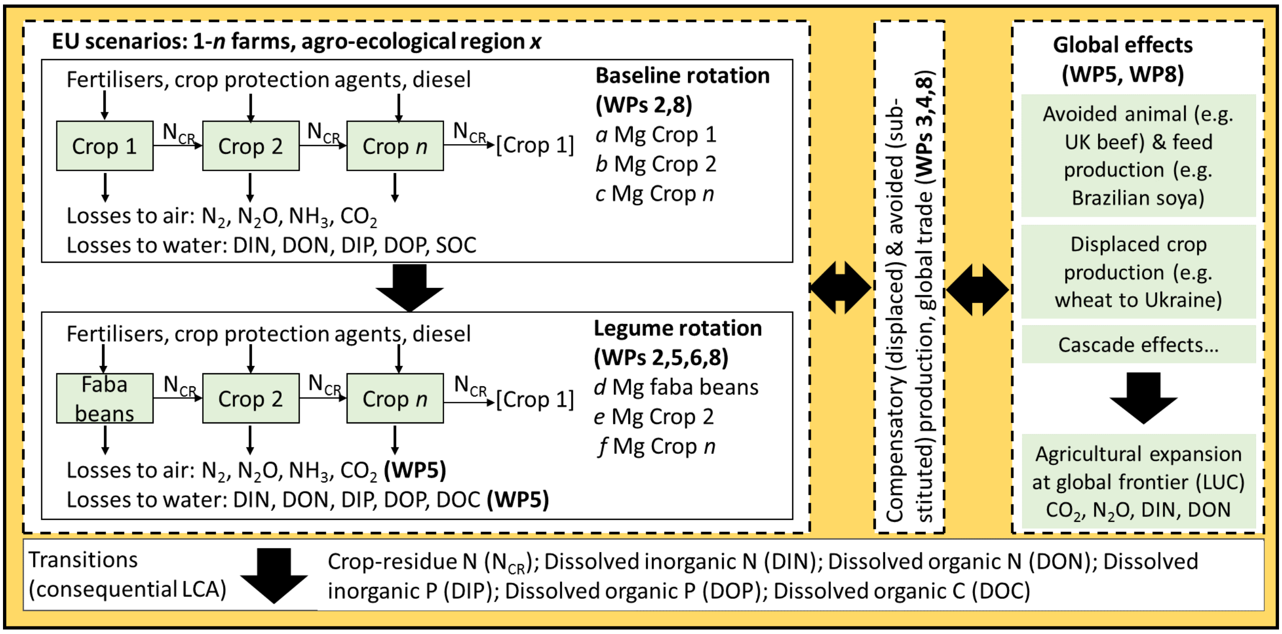

Figure 3. *Legume-modification of baseline rotations, changing mix of rotation outputs, with consequences for product substitution via global trade effects.*

In addition to direct environmental burdens of legume production calculated using attributional LCA, key factors accounted for will include changes to crop rotations and any associated displacement of conventional crop production, avoided animal feed and animal-protein production, and possible indirect land use change (land sparing) effects associated with (avoided) agricultural expansion at the global frontier. We will achieve this using a consequential LCA model for cropping systems (Styles et al., 2015) and for cattle systems (Styles et al., 2015b; 2017), detecting possible complementarities or trade-offs in terms of feed conversion efficiency and animal emissions from e.g. legume forages.

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

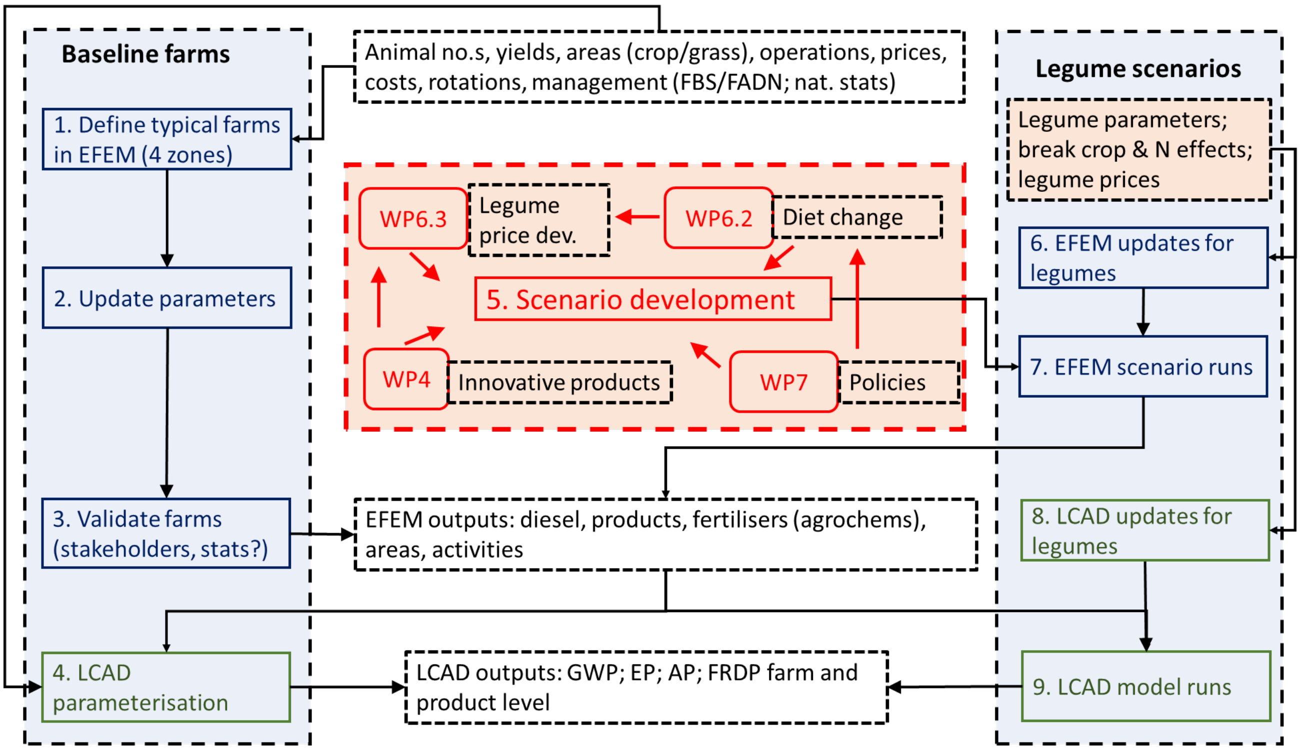

Figure 4. *Sequence of economic and environmental modelling for baseline and legume-integrated farm systems, including feedback from macro-economic (WP6) and policy (WP7) assessment.*

2.2.2 Environmental impacts

Net annual environmental loading changes will be calculated following a transition from substituted annual "baseline" food consumption to legume consumption at the EU level, relating directly to EU sustainable development targets in terms of GHG emissions, water quality, air quality, food and energy security.

Environmental loading changes will be converted into (avoided) external costs which will be combined with market effects calculated in WP6 to underpin cost-benefit analyses of legume scenarios from a public good perspective. Appropriate external costs associated with main environmental burdens will be sourced from the scientific literature and relevant policy documents, multiplied by relevant loading changes (*e.g.* carbon costs applied to tonnes CO2e emission change, eutrophication costs applied to tonnes N eq. emission change). This will enable the potential "public good" benefits of legume deployment scenarios to be presented, alongside market-based economic effects from WP6 and raw environmental loading indicators (*e.g.* tonnes year^{-1} CO2 eq. avoided).

2.2.3 Interpretation

Uncertainty can be high when undertaking consequential LCA owing to the wide range of (indirect) effects considered at different scales, but this uncertainty can in itself provide useful insight. Errors

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

will be propagated from attributional LCA and economic modelling (WP6) output ranges using Monte Carlo analyses. Sensitivity analyses will also be performed to explore responses to specific changes/uncertainties, generating new insight into hitherto unexplored relationships that only become apparent when linking multi-scale models, and highlighting priority areas for further investigation (and, indeed, areas where further investigation to improve process-level accuracy would lead to minimal overall improvements in accuracy at the value-chain-level). Extensive sensitivity analyses will be undertaken to test for key uncertainties identified in the attributional LCA, and for scenario effects (*e.g.* indirect land use change associated with imported or displaced commodities). Uncertainty will be estimated using error propagation and/or Monte Carlo analysis. The selection of relevant scenarios to test will be central to the validity of the consequential LCA results. This is described in the following section.

2.3 Farm system and scenario assessment

2.3.1 Overview of approach

Figure 4 in the previous section illustrates the iterative, multi-stakeholder and multi-disciplinary approach to baseline farm and legume scenario definition. The definition of baseline farm systems must to some extent anticipate the most likely (profitable) deployment of legumes in terms of farm typologies, which will ultimately be determined by economic modelling. At the same time, to enable upscaling of ambitious legume deployment scenarios, legume integration should be modelled for a range of major (by land area and output) farm typologies. Meanwhile, economic and LCA farm models must be parameterised using consistent data to ensure compatibility of economic and environmental indicators. According to these aforementioned principles, the following sequence of steps is proposed.

1. Select major relevant farm typologies to model on the basis of:

(i) major farming systems in each agro-climatic (AC) region;
(ii) farm systems into which priority legume crops (peas, faba beans, common beans, soya beans and forage legumes) are likely to be integrated (or for which data on legume integration are available) in each region; and,
(iii) AC farm typologies representing marginal production of animal proteins consumed in Europe, or animal feeds imported into Europe, that can be replaced by EU legume production.

2. Run farm economic model for major farm typologies in each AC region.

(i) Parameterise the EFEM model with basic data on typical yields, grass and arable areas, animal numbers, output prices and input costs (FSS and FADN data). It may be possible to use code to extract price and cost data from FADN database. Otherwise, national data should be available (*e.g.* NIX in the UK).
(ii) Predict rotations to maximise gross margin based on linear optimisation modelling.
(iii) Validate/calibrate farm characteristics based on observed cropping patterns.

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

3. Run LCAD model using EEFEM input and output data to parameterise baseline farms.

(i) Run LCAD model (Styles et al., 2015a; b) to generate data on GHG emissions, nutrient losses, energy use, *etc*, expressed at farm and product (footprint) scale.

(ii) Outputs used to characterise baseline situation (e.g. conventional diets) via attributional LCA, and also to calculate environmental credits associated with animal protein substitution in legume scenarios (consequential LCA).

4. Adapt EFEM and LCAD models to represent legume effects at farm level

(i) Obtain basic information on legume yields, management practises and establishment costs, *etc.*

(ii) Obtain data on legume-rotation-effects such as break-crop yield effects and N supply to following crops from literature, Case Studies (WP2) and stakeholder consultation.

(iii) Derive new set of conventional crop parameters to represent effect of following legumes in rotation, in terms of yield and fertiliser requirements, *etc* and parallel work and assumptions for EFEM and LCAD models.

(iv) Account for animal N excretion and enteric methane effects of legumes in dairy and cattle diets in LCAD model (CLEANER COWS project).

5. Develop scenarios of legume integration

(i) Engage with stakeholders and TRUE colleague in other work packages to identify promising/realistic legume scenarios at farm level.

(ii) Focus on legume scenarios for which we have obtained robust legume-interaction data.

(iii) Re-parameterise baseline farms in EFEM, either based directly on Case Studies (WP2) or stakeholder input, or based on exogenous price signals that can be related to wider scenarios of increased demand for EU legumes.

6. Run EFEM and LCAD models for the new legume scenarios.

(i) Generate farm-level results that can be extrapolated up in proportions relevant to the final project scenarios.

(ii) Calculate attributional footprints for legume products and apply consequential LCA to evaluate environmental loading changes for scenarios at regional/EU scale.

2.3.2 Baseline farm typologies

Baseline farm typologies into which legumes can be profitably integrated will need to be identified and parameterised. To ensure scalability of results, baseline farm typology selection will be restricted to major farm typologies from each of the three European Agro-Climatic (AC) zones being studied in the TRUE project (Table 2). Table 3 provides example typologies for dairy farms.

Table 2. *Major baseline systems across agro-climatic regions into which legumes could be integrated.*

<table>
<tr><th>Baseline system</th><th>Boreal</th><th>Atlantic</th><th>Central Europe</th><th>Mediterranean</th><th>Notes</th></tr>
<tr><td>Cropping</td><td bgcolor="green"></td><td bgcolor="green"></td><td bgcolor="green"></td><td bgcolor="green"></td><td rowspan="2">Major region-specific rotations into which legumes can be integrated</td></tr>
<tr><td>Horticulture</td><td></td><td bgcolor="green"></td><td bgcolor="green"></td><td bgcolor="green"></td></tr>
<tr><td>Dairy</td><td bgcolor="green"></td><td bgcolor="green"></td><td bgcolor="green"></td><td></td><td rowspan="2">Forage legumes and EU soya beans for feed.</td></tr>
<tr><td>Beef</td><td bgcolor="green"></td><td bgcolor="green"></td><td></td><td></td></tr>
<tr><td>Pork</td><td></td><td bgcolor="green"></td><td bgcolor="green"></td><td bgcolor="green"></td><td rowspan="2">Do intensive systems vary much by region (i.e. could “generic” pork and poultry systems be modelled)? Main change is EU soya beans for feed (could be modelled with less farm detail).</td></tr>
<tr><td>Chicken</td><td></td><td bgcolor="green"></td><td bgcolor="green"></td><td></td></tr>
</table>

Farm Accounting Data Network (FADN) data will be used to identify representative farm types for the selected regions (NUTS II level) as baseline farms, but given the low uptake of legume cropping across Europe, FADN data will provide limited insight into farm typologies most likely to take up legume cropping. Additional regional-specific information regarding agronomic and economic potential of legumes will be sought from TRUE Case Studies, from project partners, and from national institutions. In the first instance, data will be collected from one country representing each AC zone (*e.g.* Germany for Continental; UK for Atlantic; Spain for Mediterranean). This may need to be supplemented for some farm types, as *e.g.* Irish and UK dairy systems differ significantly. To ensure compatibility with macro-economic modelling, it may be possible to use CAPRI farm layer farm typologies for different regions in order to define baseline farms.

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

Table 3. *Examples of different major typologies of dairy farm in the UK.*

Milk production	System Types	Housing Type	Diet
Dairy farming	Grass based	Little or none	Mostly grazed grass minimal purchased concentrates ~ 600 kg /cow/ year
	Composite	Housing when grass not available	Partially grazed with purchased concentrates plus conserved forages in winter ~1200kg/cow/year
	Housed	Housed 100%	No grazing up to 4000kg/cow/year purchased concentrates plus conserved forages.

2.3.3 Legume scenarios

Diet change and associated legume cropping scenarios will be defined in collaboration with project partners, in particular based on macro-economic and policy analysis defined in WP6 and WP7 (Figure 4). Physical, biological and economic barriers to adoption of some form of legume crop will be identified by regions and farm types. Scenario storylines will be validated *via* consultation with all project partners and external stakeholders through a stakeholder workshop. Scenarios will need to be prospective, including ambitious legume deployment, and therefore extrapolating beyond current low rates of legume integration. Case study data will be needed to identify legume performance and interaction with conventional crops.

Legume-crop interactions will determine profitability and environmental performance at farm and product level as needed to inform legume scenarios, but won't be known until literature is reviewed to parameterise these relationships and preliminary scenarios are evaluated. A key component of the modelling work will be the benchmarking of legume-integrated rotations against baseline rotations existing before legume uptake (Figure 5). The reference time period for modelling will therefore need to be equal to the longest rotation sequence. Additional long-term effects such as soil C change can be modelled on an annualised basis using annualisation factors (*e.g.* equilibrium soil C change divided by a 20 year default transition period: IPCC, 2006).

Scale-out of legume integration across farm typologies to European (regional) level will involve feedback between farm economic (EFEM) and macro-economic (CAPRI) models. This will involve multiple runs to simulate a new equilibrium for legume scenarios. CAPRI outputs will include land use change effects that can be integrated consequential LCA at regional level when combined with extrapolations of farm typology results.

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

	BASELINE ROTATION (BEFORE)											
	1st quarter			2nd quarter			3rd quarter			4th quarter		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1st year	winter wheat 2								fallow			
2nd year					fallow	spring vegetables						
3rd year	spring vegetable		fallow							winter rape		
4th year	winter rape									winter barley		
5th year	winter barley									sugar beet		
6th year	sugar beet									winter wheat/fallow		
7th year	winter wheat or fallow (50/50)									winter wheat 2		
8th (1st) year	winter wheat 2								fallow			

	MODIFIED ROTATION (AFTER)											
	1st quarter			2nd quarter			3rd quarter			4th quarter		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1st year	winter wheat 1								fallow			
2nd year					fallow	spring vegetables						
3rd year	spring vegetable		fallow		maize					winter rye		
4th year	winter rye									winter rape		
5th year	winter rape									winter barley		
6th year	winter barley									sugar beet		
7th year	sugar beet											
8th year(1st)					maize					winter wheat 1		

Figure 5. *Example of rotation modification, indicating baseline and modified rotation sequences that need to be modelled over a reference time period.*

2.3.4 Reference farm systems

In addition to baseline farm systems, reference farm systems will also need to be modelled for the consequential LCA scenarios. Reference systems are those producing animal proteins or non-European soybeans that are likely to be substituted by expansion of EU legume production. Within the EU, these include milk, beef, pork and chicken (
Table **4**). There will be overlap with baseline farm typologies insofar as livestock systems will be considered for specific (forage) crop baselines, and reference systems will also be selected from major farm typologies.

Table 4. *Reference farm systems producing products substituted by an expansion of EU legumes.*

Reference system	Marginal EU producer(s)	Marginal global producer(s)
Milk	■	
Beef	■	
Pork	■	
Chicken	■	
Soybeans		■

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

2.4 Diet substitution

2.4.1 Overview of approach

A major aim of this study is to link both the environmental and nutritional analyses of food products, food production pathways and diet in order to advise consumers and policy makers on the benefits of legume cropping and legume products to the sustainability of food production. The 2005 Millennium Ecosystem Assessment (MEA) identified pollution from N and P, and global warming as the main environmental pressures degrading ecosystems worldwide; the anthropogenic change of ecosystems being more rapid and extensive over the past 50 years than in any comparable time in anthropogenic history (Millennium Ecosystem Assessment, 2005). The combined environmental and nutritional analysis of food production and food products adopted for TRUE has therefore focused primarily on creating new functional units for sustainability assessments based on global warming potential, eutrophication potential and Mediterranean diet adherence, and nutrient content.

Functional units quantify a particular aspect to a system being studied and provide a reference with which inputs and outputs are compared (section 2.1.1). The functional unit therefore links and compares environmental and nutritional criteria across systems and scenarios, but whereas the environmental impact of food production is usually expressed on a weight basis, nutritional data is not taken into account (Schau and Fet, 2008). Weight or volume based functional units are sufficient when comparing environmental criteria of alternative food production pathways, but when considering food products that have different nutritional roles then an alternative approach is required; one that can underline sustainability of food in terms of low life cycle impact and high nutritional content (Heller et al 2013). Smedman et al., (2010), used the nutrient density approach of Drewnowski to link healthy food profiling to global warming potential in beverage production, whilst Heller and Keoleian (2012), and Saarinen (2012) have assessed the relative contribution of a number of food items to recommended daily nutrient values compared with their environmental impact. There is however no consistent view as to a preferred functional unit, the specific requirements of these varying according to scale and food-related question (*c.f.* Heller et al., 2013).

2.4.2 Nutrient quality indices

Nutrient quality indices are a key tool in comparing food production pathways, connecting attributes of health and dietary choice, and in conjunction with environmental analyses, allow a more inclusive assessment of the sustainability of both individual food items and diet (Heller et al., 2013). By considering nutrient content of food items as a proportion of a person's daily recommended intake, then a thorough and more accurate overview of nutrient quality is possible (Drenowski et al., 2005). This may be achieved on a broad-based diet scale using indices relating food choice to 'healthy' diets, such as the Mediterranean adequacy index (MAI) (da Silva et al., 2009; Bonaccio et al., 2016), or by a more focused nutrient profiling of food items and diet using the nutrient-rich food index (NRF) (Drenowski et al., 2005; 2009; Drenowski, 2010).

The essential difference between the two approaches is that MAI assesses the adherence of a given diet to a perceived healthy diet, whilst the NRF compares the concentration of both essential

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

nutrients and ones deemed harmful, to daily recommended intake values. Both indices may be used to create useful functional units relating environmental footprints of food production pathways to health.

2.4.2.1 Mediterranean Adequacy Index (MAI)

The Mediterranean diet is considered an optimal healthy diet due to its association with better health status and lower prevalence of chronic conditions such as heart disease, cerebrovascular disease, tumours, lower serum cholesterol and neurodegenerative disease (Trichopoulou et al., 2003; da Silva et al., 2009; Sofi et al., 2010). The diet is in line with healthy eating guidelines set out by the World Health Organisation (WHO, 2003) and further scientific bodies such as the American Heart Association Nutrition Committee, and the US Department of Health and Human Services encourage adoption of the Mediterranean diet in order to reduce the risk of disease.

The diet itself is not homogenous among the Mediterranean countries, as these vary with region, food habits, cultures and recipes, but consists of several common features that are found in diets along the Mediterranean basin (Noah and Truswell, 2001). The key features are a wide consumption of fruit and vegetables, non-refined grains, legumes, cereals, nuts, fish and olive oil, coupled with a low intake of meats and dairy and a moderate consumption of wine (Bonaccio et al., 2016).

The Mediterranean Adequacy Index (MAI) has been used to study the adherence of a country or population to the Mediterranean diet, and is based simply on the ratio of food groups considered to be Mediterranean against food groups which are considered not. Higher MAI values for a country (or diet) indicate a greater adherence to the Mediterranean dietary pattern.

By definition the MAI requires daily diet data, and in the absence of standardized dietary statistics between countries, previous studies use mostly food availability data from the FAOSTAT database provided by the United Nation's Food and Agricultural Organization (FAO). These food balance sheets are produced annually for every country and using national accounts of supply and food use, provide a representation of the average availability of a food type per person in a population. In effect the data represents the sum of food products imported and produced domestically, minus the sum of food used as animal feed, food not used for human consumption and food losses in transportation, storage and processing. By dividing the amount in one given year by that particular country/region's total population, then food availability is expressed per capita (FAO, 2018). Although not perfect representations of diet, food balance sheets allow inter-country comparisons not possible with 24 hour recall diet survey statistics.

2.4.2.2 The Nutrient-rich Food Index (NRF)

The nutrient -food index (NRF) allows individual food items to be assessed and given an overall score based on how many beneficial macronutrients, vitamins and minerals each food item contains minus the concentration of nutrients perceived to be harmful in excess and hence required to be limited. By attributing individual nutrient contents to recommended daily intake values, then weight-based functional units are normalized. The sum of the nutrients gained from the product, divided by their required amounts, provides the Nutrient-rich Food Index, this algorithm can then be applied at different scales from individual food items, to meals to daily dietary intake.

Drenowski (2010) recommends a 9:3 NRF algorithm which encourages 9 nutrients (protein, fibre, vitamins A, C and E, calcium, magnesium and potassium) and limits 3 nutrients (saturated fat, added sugar and sodium). Alternate versions of the NRF algorithm are available, these using different numbers of beneficial nutrients ranging from 5 to 23, but maintaining the same 3 limiting nutrients (Drewnowski, 2010).

2.4.3 Combined Nutritional Analysis: Environmental Impact of Diet

The environmental footprint of food production and consumption is more realistically assessed if considered on the basis of individual meals or diet, where the consumption of food contributes significantly to a person's total environmental impact (Dey et al., 2007). In developed countries, food consumption contributes between 15 to 28% to overall GHG emissions (Garnett, 2011). Agriculture requires large quantities of water and inorganic fertilisers, accounting for the majority of water withdrawals from groundwater, rivers and lakes (Jagerskog et al., 2012), causing dramatic disruption to global N and phosphorous (P) cycles leading to pollution of groundwater, aquatic ecosystems and marine fisheries (Diaz *et al.*, 2008), and is a dominant cause of biodiversity loss (Foley et al., 2011). Across the EU, high dependence on SNF and overall NUE of just 20% lead to annual leaching losses of 3 Tg, NH_3-N emissions of 2.8 Tg and N_2O emissions of 0.37 Tg (Godfray et al., 2010).

Research on the relation between diet and environmental impact is in its infancy, but modelling studies have suggested that reducing the consumption of meat and other animal-derived foods can simultaneously reduce the GHG impact of the diet and reduce the risk of chronic disease (Lock et al., 2010; Scarborough et al., 2012). Correlations of reduced environmental impacts of production with improved nutrient quality of food products are possible using functional unit bases representing key nutrient content such as weighted nutrient density scores or indices (cf. Drenowski, 2010; Aresanault et al., 2012; Heller et al., 2013; Primavesi et al., 2014; Bonaccio et al., 2016). In TRUE both the MAI and NRF indices will be combined with environmental LCA data to calculate the optimum nutrition per environmental impact for a range of protein sources, individual meals and daily diets.

Grunert et al., (2014) highlighted a 'moderately high level of concern' for sustainable food production by consumers, and per capita consumption of protein may provide an aggregated means of examining the intake of both animal and plant products. One of the key recommendations of the 2007 report on Food, Nutrition, Physical Activity, and the Prevention of Cancer (World Cancer Research Fund, 2007), is to increase the intake of non-starchy plant foods to at least 600g d^{-1} with legumes contributing at least 25g d^{-1}. The adoption of a healthy diet across Europe though, is far from ideal. In the most recent systematic assessment of global diets, increased consumption of unhealthy food items has occurred over the past 20 years for high, medium and low-income countries overall (Imamura *et al.,* 2015), a switch away from the consumption of plant protein to animal protein being a common observation for medium to high-income earners (Messina *et al.,* 1999). Over the last 50 years the quantity of pig meat, poultry and dairy consumed in the EU has increased significantly, with the consumption of poultry in 2007

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

being over 4 times what it was in 1961, and similarly the average consumption of animal protein being 50% higher than in the early 1960s (Westenhoek et al., 2015). The high intake of animal products in Western diets leads to a saturated fat intake 40% higher than the maximum limit and a red meat consumption that is twice the maximum limit (Linseisen et al., 2009; Ocké et al., 2009; Pan et al., 2012). Daily consumption rates for Europe are illustrated in Table? Based on FAO food availability data.

Table 5. *Mean Availability of Food Groups in Europe (2000 to 2013).*

	Mean availability of food groups (kcal per person per day) over 2000 to 2013							
	Northern Europe		Southern Europe		Western Europe		Eastern Europe	
	mean	se	mean	se	mean	se	mean	se
CEREALS	890.7	5.6	978.9	4.3	847.9	7.86	1143.6	5.8
MEATS	421.1	2.8	373.1	3.8	402.4	4.10	265.9	6.5
ANIMAL FATS	159.7	3.1	119.4	2.2	271.0	3.60	129.9	1.6
FISH AND SEA FOOD	48.6	0.3	55.5	0.6	50.4	0.51	35.1	1.6
FRUITS	116.6	2.9	150.4	2.7	111.6	1.05	68.6	2.5
VEGETABLES	242.9	3.4	200.6	3.3	196.4	2.29	279.6	1.5
OLIVE OIL	18.6	1.2	234.4	4.6	25.1	0.76	2.6	0.4
PULSES	49.4	1.7	57.0	0.5	29.2	0.81	26.9	0.6
NUTS	17.0	0.9	38.8	0.7	36.2	0.57	8.1	0.5
VEGETABLE OILS	374.5	4.6	326.4	7.9	421.5	4.42	299.9	7.4
SUGAR AND SWEETENERS	377.2	4.5	289.9	1.3	436.6	3.14	404.9	3.2
MILK	356.0	1.1	280.6	0.9	347.3	1.76	266.6	2.8
EGGS	41.9	0.5	44.1	0.4	50.9	0.54	51.9	0.8
ALCOHOLIC DRINK	178.9	4.1	149.6	3.8	203.4	4.51	170.0	6.5
TOTAL	**3293.1**	**36.7**	**3298.6**	**37.0**	**3429.9**	**35.91**	**3153.5**	**41.7**

2.4.3.1 Alternative EU Diets

The gross over consumption within the EU and the West, raise questions around the implication for the environment and human health if consumers replace part of their meat. Dairy and egg intake with plant-based proteins. The Nitrogen on the Table Report (Westenhoek et al., 2015) explored six alternative diet scenarios based on current consumption in the EU. These diets presented a 25% or 50% decrease in the intake of beef, dairy, pig meat, poultry and eggs. The report compensated the reduced intake of protein by increasing the intake of cereals but did not consider other plant-based protein sources such as legumes as compensators. Legumes have been championed as pioneer plants; a means of sustainably intensifying agriculture, improving nutrient efficiency and closing yield gaps (Iannetta et al., 2013). They have traditionally played an important role in global diets, although in the West they tend to play a minor role (Messina, 1999; Kearney, 2010). They are however an excellent source of protein, fibre and micronutrients and consumption of legumes has been correlated with a reduction in cancer and improved health over all (Messina et al., 1999; Polak, Phillips and Campbell, 2015; Li and Mao, 2017). Alternative diet scenarios will be analysed in TRUE based on protein consumption and will incorporate the combined nutritional and environmental indices approach mentioned above, as will novel legume products and legume meal recipes provided by the specific Case Studies.

2.4.4 Initial meta-analysis of agricultural protein production

Development of functional units incorporating both environmental and nutritional aspects to food pathways necessitate a systematic review of the life cycle impacts involved. Both global warming and eutrophication potential were chosen in this study, these being the most common variables

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

published in LCA studies, and ones representing opposite extremes in scale. Protein sources chosen depended on the availability of LCA data, incorporating 28 food types for global warming potential (GWP) and 24 for eutrophication potential.

The systematic review strategy employed was based on that followed by Clune et al., (2017) incorporating the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) protocol of Liberati et al., (2009). The literature search was carried out from May to July 2017 and encompassed data from peer reviewed journal papers, industry and government reports, laboratory test results, publicly available databases, conference proceedings and Environmental Product Declarations (EPD). A diagram of the full systematic process is given in Figure 6.

Data collected were annotated under the following headings:

- Food Group (dairy/meat/meat substitute etc.)
- Food Type (milk/mozzarella/pork/ etc.)
- Food Sub Category (legume/cheese/fish/tree nuts/cereals etc.)
- Geographic Region
- Year of Publication
- Report Type (EPD, journal article, report etc.)
- kg CO_2e kg^{-1} raw product (GWP) or g PO_4^{3-}e kg^{-1} raw product (eutrophication potential)
- Additional Notes (farming methods, feed type, species, cultivar etc.)
- Full Reference

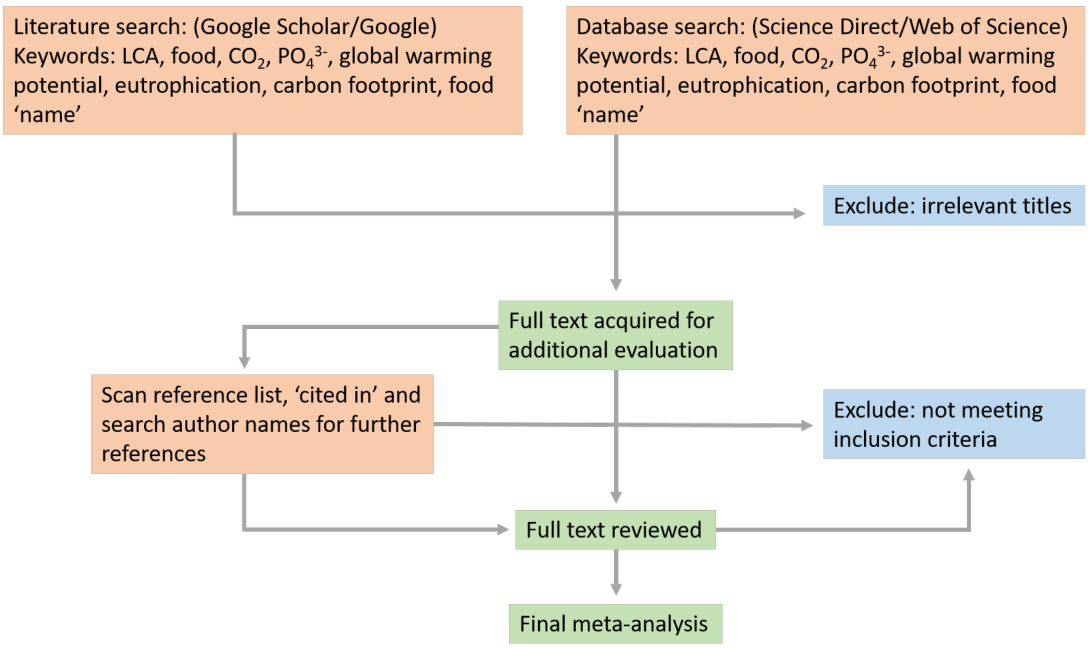

Figure 6. *Outline of systematic literature review.*

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

Table 6. *Conversion of GWP alternative functional units to bone free meat (BFM). Adapted from Clune et al., 2017.*

Ratio	Beef	Sheep	Pork	Chicken	Fish	Rabbit
Hot standard carcass weight: carcass weight	1:0.98	1:0.98	NA	NA	NA	NA
Live weight: bone free meat	1:0.485	1:0.43	1:0.43	1:0.54	1:0.625	1:0.52
Carcass weight: bone free meat	1:0.695	1:0.66	1:0.59	1:0.77		1:0.85

A variety of LCA system boundaries needed to be accounted for in the data collected, to relate to various functional units (Table 6). These ranged from:

- Farm to farm gate
- Farm to slaughter house
- Farm to regional distribution center (RDC)
- Farm to retail
- Farm to cooked product
- Farm to human excrement

The farm gate boundary was chosen to enable comparison between data, with inputs and outputs considered illustrated in
Figure **7**. Foods that required primary processing (milk, cheese, Quorn and butter) the system boundary was considered to be at the completion of primary processing. Where system boundaries finished post farm gate, and the farm gate sub-category had not been identified, the median values for post gate stages were subtracted from the sum to give apparent farm gate boundaries. Median values for post-gate GHG emissions from key LCA stages are given in

Table *7* (adapted from Clune et al., 2017).

Table 7. *Post farm-gate emission data (Clune et al., 2017).*

LCA stages occurring post farm gate	No of GWP values	Median GWP (kg CO_2e kg^{-1})	Mean GWP (kg CO_2e kg^{-1})	SD
Processing meats	5	0.59	0.66	0.14
Processing vegetables	15	0.06	0.07	0.04
Packaging	8	0.05	0.06	0.06
Transport to RDC	21	0.09	0.13	0.19

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

Retail	20	0.04	0.1	0.25

2.4.5 Mediterranean Adequacy Index (MAI) methodology for TRUE

2.4.5.1 Compilation of Food Balance Sheet Data

Food balance sheet data (kcal capita-1day-1) of all food types available in Europe in 2013 was downloaded from the FAOSTAT database and grouped according to Kearney, (2010). Here food types were sorted into the following categories: cereals, roots and tubers, sugars and honey, pulses, nuts and oil seeds, oils and fats, vegetables, fruits, meats, dairy, eggs, fish. Categories were also added for: stimulants, spices, alcoholic drinks.

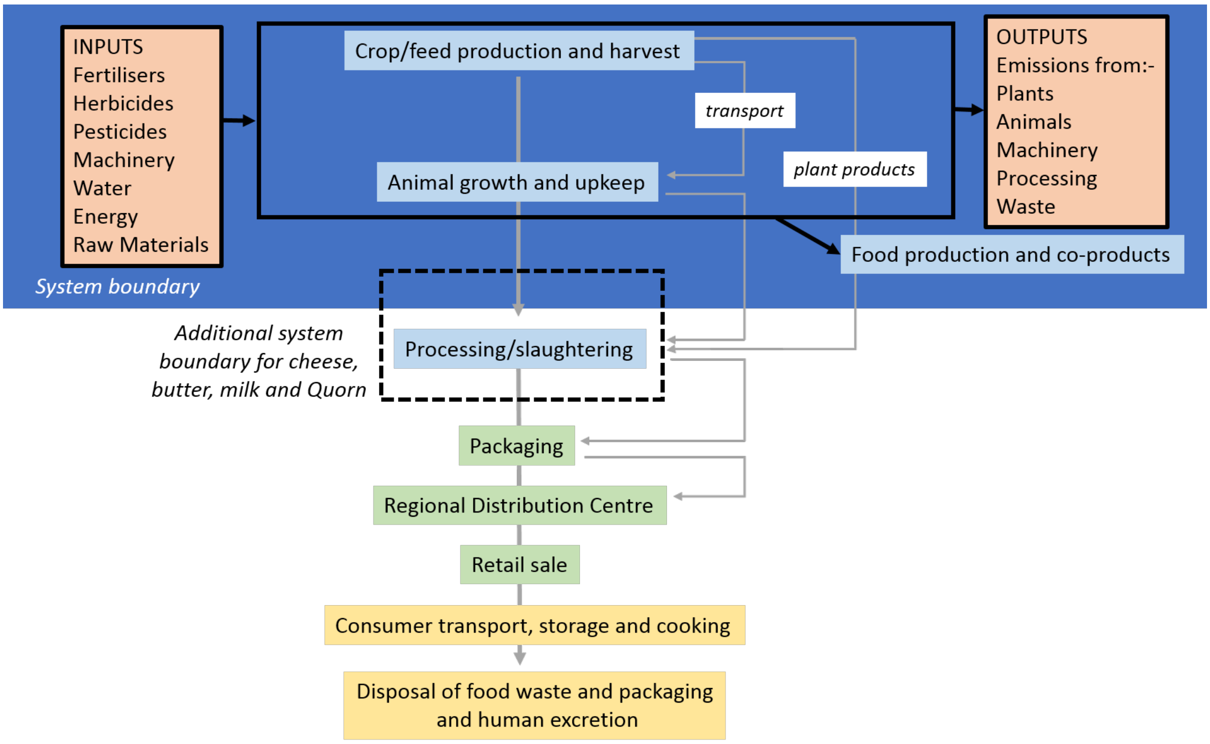

Figure 7. *System boundaries for meta-analysis of published LCA data for protein sources (adapted from Clune et al., 2017).*

2.4.5.2 Mediterranean Diet Groupings

The MAI was calculated from the food balance sheet data incorporating baseline and alternative European diets. Here the total kcal capita-1 day-1 value of the Mediterranean diet food groups was divided by the kcal capita^{-1} day^{-1} total of the non-Mediterranean diet food groups. For this study Mediterranean diet food groups were defined as olive oil, olives, cereals, starchy roots, herbs and spices, fruits, vegetables, nuts, fish, legumes and wine. Non-Mediterranean food groups were defined as fats (excluding olive oil), sugar and sweeteners, alcoholic beverages (excluding wine), meat, sugar crops, oil crops, stimulants and animal fats.

As an example of the data produced, Table 8 illustrates the change in the average MAI between 1963-1973, and 2003 – 2013 for Ireland and Italy where a decline in adherence to the Mediterranean diet has occurred for both countries (data from Byrne, 2018).

Table 8. *Mediterranean Adequacy Index (MAI) scores (± SE) for Irish and Italian diets between 1963-73, and 2003-2013 (Byrne, 2018).*

Country	Mediterranean Adequacy Index (MAI)	
Years	**1963-1973**	**2003-2013**
Ireland	0.86 ± 0.02	0.41 ± 0.01
Italy	2.72 ± 0.10	1.61 ± 0.04

2.4.6 Nutrient-Rich Food Index (NRF)

The NRF focuses on nutrient density, either as nutrients per calorie, or per gram of product. Drewnowski (2010) recommends an algorithm which encourages 9 nutrients and limits 3 nutrients (9:3 NRF), whereas our study incorporates both this and an 11:3 NRF.

2.4.6.1 Systematic selection of foods and reference nutrients

The nutrient composition values of individual food products, food items and raw ingredients were obtained from both the USDA National Nutrient Database for Standard Reference (version 28) (USDA, 2017) and listings provided by food manufacturers and restaurants (SelfNutrientData, 2018). Each food listing provides nutritional information regarding calorie content, carbohydrates, fats and fatty acids, protein and amino acids, vitamins, minerals and sterols. Data requirements and daily reference values pertinent to TRUE 9:3 and 11:3 NRF calculations are given in

Table **9**. Several of the nutrients to encourage (protein, fibre, vitamins A and C) are recommended in the FDA definition of 'healthy foods' (FDA 2016), the remaining nutrients to encourage being selected according to recommendations within 'Dietary Guidelines for Americans' (USDA and US Department of Health and Human Services, 2005). The choice of nutrients to limit (saturated fat, added sugar, sodium) was according to Drewnowski, 2005; Arambepola et al., 2008; Drewnowski and Fulgoni, 2008 and Maillot et al., 2008.

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

Table 9. *Data requirements and daily reference values pertinent to TRUE 9:3 and 11:3 NRF calculations (cf Drewnowski, 2005, 2010; Drewnowski et al., 2008).*

Nutrients to encourage	NRF 9:3	NRF 11:3	Recommended Daily Value (RDV)	Maximum Recommended Value (MRV)
Protein	+	+	50 g	
Fibre	+	+	25 g	
Vitamin A	+	+	5000 IU	
Vitamin B-12		+	6 µg	
Vitamin C	+	+	60 mg	
Vitamin E	+	+	20 mg	
Calcium	+	+	1000 mg	
Iron	+	+	18 mg	
Potassium	+	+	3500 mg	
Magnesium	+	+	400 mg	
Zinc		+	15 mg	
Nutrients to limit		+		
Saturated Fat	+	+		20 g
Sodium	+	+		2400 mg
Added Sugar	+	+		50 g

The NRF11:3 compliments the 9:3 index in having two extra nutrients to encourage; vitamin B12 and zinc. Meat is the main source of vitamin B12 in humans, and with the increasing popularity of vegan diets then nutritional deficiency in vitamin B12 is becoming common (Kuhne et al., 1990; Stabler and Allen, 2004). Inclusion of zinc to the nutrient list was based on its importance in subcellular metabiolism and the common observation of zinc deficiency in everyday diets (Hambridge, 2000; Wessels and Brown, 2010).

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

2.4.6.2 Calculation of NRF values

Standard procedure was used to calculate NRF scores for each food item/protein source (Sluik et al., 2015). NRF scores were calculated either per 100kcals or per 100g of food item using equations given in Table 10. The percentage daily values (%DV) were capped at 100% for each nutrient to prevent disproportionate weighting of a single nutrient biasing the index score (Fulgoni et al., 2009).

Table 10. *Nutrient Rich Food Index (NRF) Algorithms.*

Model	Algorithm	Notes
NRF 9:3 sub-score		
NRF 9:3$_{100g}$	$\sum_{1-9}(nutrient_i/DV_i) \times 100$	Nutrient$_i$ = nutrient per 100g DV$_i$ = daily value for the nutrient (RDV) S$_i$ = calories per 100g
NRF 9:3$_{100kcal}$	$\sum_{1-9}(nutrient_i/DV_i)/S_i \times 100$	
NRF 11:3 sub-score		
NRF 11:3$_{100g}$	$\sum_{1-11}(nutrient_i/DV_i) \times 100$	
NRF 11:3$_{100kcal}$	$\sum_{1-11}(nutrient_i/DV_i)/S_i \times 100$	
LIM sub-score		
LIM$_{100g}$	$\sum_{1-3}(nutrient_i/MRV_i) \times 100$	MRV$_i$ = maximum recommended value for the nutrient (grams)
LIM$_{100kcal}$	$\sum_{1-3}(nutrient_i/MRV_i)/S_i \times 100$	
NRF models		
NRF 9:3$_{100g}$	$NRF\ 9{:}3_{100g} - LIM_{100g}$	
NRF 9:3$_{100kcal}$	$NRF\ 9{:}3_{100kcal} - LIM_{100kcal}$	
NRF 11:3$_{100g}$	$NRF\ 11{:}3_{100g} - LIM_{100g}$	
NRF 11:3$_{100kcal}$	$NRF\ 11{:}3_{100kcal} - LIM_{100kcal}$	

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

2.4.7 Nutrient Density Environmental Impact Indices

Simple algorithms combining nutrient density of food items/protein sources with each of the environmental indices were developed for the purpose of this study. Environmental impacts considered were the mean global warming potential and eutrophication potential. Nutrient density indices were both the NRF9:3 and NRF11:3 functions as shown above. Necessary algorithms to calculate both the Nutrient Density Global Warming Potential, and Nutrient Density Eutrophication Potential are given in Table 11. Additional indices are to be developed combining the Mediterranean Adequacy Index of diets (as defined by FAO food balance sheet data) with the global warming and eutrophication potentials calculated as above.

Table 11. *Nutrient Density Environmental Impact (NDEI) Indices for NDGWP100g, NDGWP100kcal, NDEP100g and NDEP100kcal*

Model	Algorithm	Notes
NDGWP		
$NDGWP_{100g}$	$NRF\ 11{:}3_{100g}/GWP_{100g}$	GWP_{100g} = kg CO_2e $100g^{-1}$ product
$NDGWP_{100kcal}$	$NRF\ 11{:}3_{100kcal}/GWP_{100kcal}$	$GWP_{100kcal}$ = kg CO_2e $100kcal^{-1}$ product
NDEP		
$NDEP_{100g}$	$NRF\ 11{:}3_{100g}/EP_{100g}$	EP_{100g} = g PO_4^{3-}e 100^{-1} product
$NDEP_{100kcal}$	$NRF\ 11{:}3_{100kcal}/EP_{100kcal}$	$EP_{100kcal}$ = g PO_4^{3-}e $100kcal^{-1}$ product

References

Arambepola, C.; Scarborough, P.; Rayner, M. 2008. Validating a nutrient profile model. Public Health Nutrition, 11, 371–8.

Arsenault, J.E.; Fulgoni, V.L.; Hersey, J.C.; Muth, M.K. 2012. A novel approach to selecting and weighting nutrients for nutrient profiling of foods and diets. Journal of the Academy of Nutrition and Dietetics, 112, 1968–1975.

Baggs, E. M.; Rees, R. M.; Smith, K. A.; Vinten, A. J. A. 2006. Nitrous oxide emission from soils after incorporating crop residues. Soil Use and management, 16 (2), 82–87.

Beaudoin, N.; Saad, J. K.; Van Laethem, C.; Machet, J. M.; Maucorps, J.; Mary, B. 2005. Nitrate leaching in intensive agriculture in Northern France: Effect of farming practices, soils and crop rotations. Agriculture Ecosystem and Environment, 111 (1–4), 292–310.

Boeing, H.; Bechthold, A.; Bub, A.; Ellinger, S.; Haller, D.; Kroke, A.; Leschik-Bonnet, E.; Müller, M. J.; Oberritter, H.; Schulze, M.; et al. 2012. Critical review: vegetables and fruit in the prevention of chronic diseases. European Journal of Nutrition, 51 (6), 637–663.

Bonaccio, M.; Donati, M.; Iacoviello, L.; De Gaetano, G. 2016. Socioeconomic Determinants of the Adherence to the Mediterranean Diet at a Time of Economic Crisis: The Experience of the MOLI-SANI Study1. Agriculture and Agricultural Science Procedia, 8, 741-747.

Byrne, A. 2018. Nutrient Analyses of European Diets: Ireland and Italy. Trinity College, BA Thesis. Department of Zoology. Trinity College Dublin.

Campiglia, E.; Mancinelli, R.; Radicetti, E.; Marinari, S. 2011. Legume cover crops and mulches: effects on nitrate leaching and nitrogen input in a pepper crop (*Capsicum annuum* L.). Nutrient Cycling in Agroecosystems, 89 (3), 399–412.

Clune, S.J.; Crossin, E.; Verghese, K. 2017. Systematic review of greenhouse gas emissions for different fresh food categories. Journal of Cleaner Production, 140(2), 766-783. DOI: 10.1016/j.jclepro.2016.04.082

Da Silva, R.; Bach-Faig, A.; Quintana, B. R.; Buckland, G.; De Almeida, M. D. V.; Serramajem, L. 2009. Worldwide variation of adherence to the Mediterranean diet, in 1961–1965 and 2000–2003. Public Health Nutrition, 12, 1676-1684.

Darmon, N.; Drewnowski, A. 2015. Contribution of food prices and diet cost to socioeconomic disparities in diet quality and health: a systematic review and analysis. Nutrition Reviews, 73 (10), 643–660.

Dey, C.; Berger, C.; Foran, B.; Foran, M.; Joske, R.; Lenzen, M.; Wood, R. 2007. Household environmental pressure from consumption: An Australian environmental atlas. In, 2007, Birch, G. (Ed.), Water, Wind, Art and Debate: How Environmental Concerns Impact on Disciplinary Research. Sydney University Press, Sydney.

Diaz, R. J.; Rosenberg, R. 2008. Spreading dead zones and consequences for marine ecosystems. Science, 321 (5891), 926–929.

Drewnowski, A. 2005. Concept of a nutritious food: toward a nutrient density score. American Journal of Clinical Nutrition, 82, 721–32.

Drenowski, A. 2009. Obesity, diets, and social inequalities. Nutrition Reviews, 67, Suppl. 1: S36-9. DOI: 10.1111/j.1753-4887.2009.00157x.

Drewnowski, A. 2010. The Nutrient Rich Foods Index helps to identify healthy, affordable foods. The American Journal of Clinical Nutrition, 91(4), 1095-1101.

Drewnowski, A..; Darmon, N. 2005. The economics of obesity: dietary energy density and energy cost. The American Journal of Clinical Nutrition, 82(1), 265S-273S.

Drewnowski A.; Fulgoni, V. 2008. Nutrient profiling of foods: creating a nutrient-rich food index. Nutrition Reviews, 66, 23–39.

FAO. 2018. FAOSTAT Food Balance Sheet Database: http://www.fao.org/faostat/en/#data/FBS.

FDA. 2016. Use of the term “Healthy” in the labelling of human food products: Guidance for Industry. Available online at: https://www.fda.gov/downloads/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/UCM521692.pdf [last accessed 7.12.17]

Finkbeiner, M.; Inaba, A.; Tan, R. B. H.; Christiansen, K.; Klüppel, H.-J. 2006. The New International Standards for Life Cycle Assessment: ISO 14040 and ISO 14044. International Journal of LCA, 11(112), 80–85. https://doi.org/10.1065/lca2006.02.002

Foley, J.A.; Ramankutty, N.; Brauman, K.A.; Cassidy, E.S.; Gerber, J.S.; Johnston, M.; Mueller, N.D.; O’Connell, C.; Ray, D.K.; West, P.C.; Balzer, C.; Bennett, E.M.; Carpenter, S.R.; Hill, J.; Monfreda, C.; Polasky, S.; Rockström, J.; Sheehan, J.; Siebert, S.; Tilman, D.; Zaks, D.P.M. 2011. Solutions for a cultivated planet. Nature, 478, 337-342.

Frimpong, K. A.; Yawson, D. O.; Baggs, E. M.; Agyarko, K. 2011. Does incorporation of cowpea-maize residue mixes influence nitrous oxide emission and mineral nitrogen release in a tropical luvisol? Nutrient Cycling in Agroecosystems, 91 (3), 281–292.

Fulgoni, V.L.; Keast D.R.; Drewnowski, A. 2009. Development and validation of the Nutrient Rich Foods Index: a tool to measure nutrient density of foods. Journal of Nutrition, 139, 1549–54.

Garnett, T. 2011. Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? Food Policy, 36, S23-S32.

Godfray, H.; Charles J., et al. 2010 Food security: the challenge of feeding 9 billion people. Science, 327, 812-818.

Gomes, J.; Bayer, C.; de Souza Costa, F.; de Cássia Piccolo, M.; Zanatta, J. A.; Vieira, F. C. B.; Six, J. 2009. Soil nitrous oxide emissions in long-term cover crops-based rotations under subtropical climate. Soil Tillage Research, 106 (1), 36–44.

Grunert, K.G.; Hieke, S.; Wills, J. 2014. Sustainability labels on food products: Consumer motivation, understanding and use. Food Policy, 44, 187.

Hambidge, M. 2000. Human zinc deficiency. The Journal of Nutrition, 130(5), 1344-1349.

Havlík, P.; Valin, H.; Herrero, M.; Obersteiner, M.; Schmid, E.; Rufino, M. C.; Mosnier, A.; Thornton, P. K.; Böttcher, H.; Conant, R. T.; et al. 2014. Climate change mitigation through livestock system transitions. Proceedings of the National Academy of Science U. S. A., 111 (10), 3709–3714.

Heller, M. C.; Keoleian, G. A. 2015. Greenhouse Gas Emission Estimates of U.S. Dietary choices and Food Loss. Journal of Industrial Ecology, 19 (3), 391–401.

Heller, M.C.; Keoleian, G. 2012, October. A novel nutrition-based functional equivalency metric for comparative life cycle assessment of food. In Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector, LCA Food 2012, 1-4.

Heller, M. C.; Keoleian, G. A.; Willett, W. C. 2013. Toward a Life Cycle-Based, Diet-level Framework for Food Environmental Impact and Nutritional Quality Assessment: A Critical Review. Environtal Science & Technology, 47 (22), 12632–12647.

Hoekstra, A. Y. 2016. A critique on the water-scarcity weighted water footprint in LCA. Ecological Indicators, 66, 564–573.

Iannetta, P.P.M.; Begg, G.; James, E.K.; Smith, B.; Davies, C.; Karley, A.; del Egido, L.L.; Hawes, C.; Young, M.; Ramsay, G.; Birch, A.N.E. 2013. Sustainable intensification: a pivotal role for legume supported cropped systems. Aspects of Applied Biology, 121, 73-82.

Imamura, F.; O'Connor, L.; Ye, Z.; Mursu, J.; Hayashino, Y.; Bhupathiraju, S.N.; Forouhi, N.G. 2015. Consumption of sugar sweetened beverages, artificially sweetened beverages, and fruit juice and incidence of type 2 diabetes: systematic review, meta-analysis, and estimation of population attributable fraction. British Medical Journal, 351, doi: 10.1136/bmj.h3576

Jägerskog, A.; Jønch Clausen, T. (eds.) 2012. Feeding a thirsty world – challenges and opportunities for a water and food secure future. Report Nr. 31. SIWI, Stockholm.

Jensen, E. S.; Hauggaard-Nielsen, H. 2003. How can increased use of biological N_2 fixation in agriculture benefit the environment? Plant Soil, 252 (1), 177–186.

Jensen, E. S.; Peoples, M. B.; Boddey, R. M.; Gresshoff, P. M.; Hauggaard-Nielsen, H. J.R. Alves, B.; Morrison, M. J. 2012. Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review. Agrononmy for Sustainable Development 32 (2), 329–364.

Jonker, J. S.; Kohn, R. A.; High, J. Dairy herd management practices that impact Nitrogen utilization efficiency. Journal of Dairy Science, 85 (5), 1218–1226.

Kearney, J. 2010. Food consumption trends and drivers. Philosophical Transactions of the Royal Society B: Biological Sciences, 365, 1554, 2793-2807.

Köpke, U.; Nemecek, T. Ecological services of faba bean. F. Crop. Research, 115 (3), 217–233.

Kuhne, T.; Bubl, R.; Baumgartner, R. 1991. Maternal vegan diet causing a serious infantile neurological disorder due to vitamin B12 deficiency. European Journal of Pediatrics, 150, 205–208.

Leach, A. M.; Galloway, J. N.; Bleeker, A.; Erisman, J. W.; Kohn, R.; Kitzes, J. 2012. A nitrogen footprint model to help consumers understand their role in nitrogen losses to the environment. Environmental Development. 1 (1), 40–66.

Li,J.; Mao, Q.Q. 2017. Legume intake and risk of prostate cancer: A meta-analysis of prospective cohort studies. Oncotarget, 8(27), 44776-44784. doi: 10.18632/oncotarget.16794

Liberati, A.; Altman, D.G.; Tetzlaff, J.; Mulrow, C.; Gøtzsche, P.C.; Ioannidis, J.P.A.; Clarke, M.; Devereaux, P.J.; Kleijen, J.; Moher, D. 2009. The PRISMA statement for reporting systematic reviews and meta-analyses of Studies that evaluate health care interventions: explanation and elaboration. British Medical Journal, 339, b2700. doi.org/10.1371/journal.pmed.1000100

Linseisen, J.; Welch, A.A.; Ocké, M.; Amiano, P.; Agnoli, C.; et al. 2009. Dietary fat intake in the European Prospective into Cancer and Nutrition: Results from the 24-h dietary recalls. European Journal of Clinical Nutrition, 63, S61-S80. doi: 10.1038/ejcn.2009.75

Lock, K.; Smith, R.D.; Dangour, A.D.; Keogh-Brown, M.; Pigatto, G.; Hawkes, C.; Fisberg, R.M.; Chalabi, Z. 2010. Chronic diseases: Chronic diseases and development 2. Health, agricultural, and economic effects of adoption of healthy diet recommendations. Lancet, 376, 1699–709.

Lüscher, A.; Mueller-Harvey, I.; Soussana, J. F.; Rees, R. M.; Peyraud, J. L. 2014. Potential of legume-based grassland-livestock systems in Europe: a review. Grass Forage Science, 69 (2), 206–228.

Maillot, M.; Darmon, N.; Darmon, M.; Lafay, L.; Drewnowski, A. 2007. Nutritional dense food groups have high energy costs: an econometric approach to nutrient profiling. Journal of Nutrition, 137(7), 1815-1820.

Messina, M.J., 1999. Legumes and soybeans: Overview of their nutritional profiles and health effects. The American Journal of Clinical Nutrition, 70, 439S-450S. doi: 10.1093/ajcn/70.3.439s.

Millennium Ecosystem Assessment (Program). 2005. Ecosystems and human well-being. Washington, D.C., Island Press.

Morton, D. C.; DeFries, R. S.; Shimabukuro, Y. E.; Anderson, L. O.; Arai, E.; del Bon Espirito-Santo, F.; Freitas, R.; Morisette, J. 2006. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. Proceedings of the National Academy of Sciences U. S. A., 103 (39), 14637–14641.

Muñoz, I.; Milà i Canals, L.; Fernández-Alba, A. R. 2010. Life cycle assessment of the average Spanish diet including human excretion. International Journal of Life Cycle Assessment, 15 (8), 794–805.

Nemecek, T.; Dubois, D.; Huguenin-Elie, O.; Gaillard, G. 2011. Life cycle assessment of Swiss farming systems: I. Integrated and organic farming. Agricicultural Systems, 104 (3), 217–232.

Noah, A.; Truswell, A. S. 2001. There are many Mediterranean diets. Asia Pacific Journal of Clinical Nutrition, 10, 2-9.

Nyfeler, D.; Huguenin-Elie, O.; Suter, M.; Frossard, E.; Connolly, J.; Lüscher, A. 2009. Strong mixture effects among four species in fertilized agricultural grassland led to persistent and consistent transgressive overyielding. Journal of Applied Ecology, 46 (3), 683–691.

Ocké, M.C.; Larrañaga, N.; Grioni, S.; van den Berg, S.W.; Ferrari, P.; et al. 2009. Energy intake and sources of energy intake in the European prospective investigation into cancer and nutrition. European Journal of Clinical Nutrition, 63, S3-S15. doi: 10.1038/ejcn.2009.72

Pan, A.; Sun, Q.; Bernstein, A.M.; Schulze, M.B.; Manson, J.E.; Stampfer, M.J.; Willett, W.C.; Hu, F.B. 2012. Red meat consumption and mortality: Results from 2 prospective cohort studies. Archives of Internal Medicine, 172, 555-563. doi: 10.1001/archinternmed.2011.2287

Polak, R.; Phillips, E.M.; Campbell, A. 2015. Legumes: Health benefits and culinary approaches to increase intake. Clinical Diabetes, 33(4), 198-205.

Primavesi, L.; Caccavelli, G.; Ciliberto, A.; Pauze, E. 2014. Nutrieconomic model can facilitate healthy and low-cost food choices. Public Health Nutrition, 18(5), 827-835.

Saarinen, M., 2012. Nutrition in LCA: are nutrition indexes worth using? In: 8th International Conference on Life Cycle Assessment in the Agri-food Sector, October 1-4, 2012 Saint-Malo, France: Proceedings/Eds. Michael S. Corson, Hayo MG van der Werf. INRA.

Scarborough, P.; Appleby, P. N.; Mizdrak, A.; Briggs, A. D. M.; Travis, R. C.; Bradbury, K. E.; Key, T. J. 2014. Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK. Clim. Change, 125 (2), 179–192.

Schau, E.M.; Fet, A.M. 2008. LCA studies of food products as background for environmental product declarations. The International Journal of Life Cycle Assessment, 133, 255-264.

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

SelfNutrientData, 2018. NUTRIENTDATASELF Database. Available: http://nutritiondata.self.com/

Sluik, D.; Streppel, M. T.; Van Lee, L.; Geelen, A.; Feskens, E. J. 2015. Evaluation of a nutrient-rich food index score in the Netherlands. Journal of Nutritional Science, 4-14. DOI:10.1017/jns.2015.4

Smith, L.A.; Goncalves dos Reis, B.; Olokosi O.A.; Houdijk, J.G.M. 2015. Bean starch concentrates as a home grown alternative to soya bean meal in grower and finisher pig diets. Proceedings of the British Society of Animal Science, 6 (20), 173.

Sofi, F.; Abbate, R.; Gensini, G. F.; Casini, A. 2010. Accruing evidence on benefits of adherence to the Mediterranean diet on health: an updated systematic review and meta-analysis. The American Journal of Clinical Nutrition, 92, 1189-1196.

Stabler, S.P.; Allen, R.H. 2004. Vitamin B12 deficiency as a worldwide problem. Annual Review Nutrition, 24, 299-326.

Styles, D.; Gibbons, J.; Williams, A. P.; Dauber, J.; Stichnothe, H.; Urban, B., Jones, D. L. 2015. Consequential life cycle assessment of biogas, biofuel and biomass energy options within an arable crop rotation. Global Change Biology Bioenergy, 7(6), 1305–1320. https://doi.org/10.1111/gcbb.12246

Styles, D.; Gibbons, J.; Williams, A. P.; Stichnothe, H.; Chadwick, D. R.; Healey, J. R. 2015. Cattle feed or bioenergy? Consequential life cycle assessment of biogas feedstock options on dairy farms. Global Change Biology Bioenergy, 7(5), 1034–1049. https://doi.org/10.1111/gcbb.12189

Styles, D.; Gonzalez-Mejia, A.; Moorby, J.; Foskolos, A.; Gibbons, J. 2017. Climate mitigation by dairy intensification depends on intensive use of spared grassland. Global Change Biology, 681-693. https://doi.org/10.1111/gcb.13868

Trichopoulou, A.; Costacou, T.; Bamia, C.; Trichopoulos, D. 2003. Adherence to a Mediterranean diet and survival in a Greek population. New England Journal of Medicine, 348, 2599-2608.

US Department of Agriculture, US Department of Health and Human Services, 2005. Dietary guidelines for Americans. 6th ed. Washington, DC: US Government Printing Office Available from: http://www.health. gov/dietaryguidelines/ [Accessed 7 November 2017].

Vanham, D.; Mekonnen, M. M.; Hoekstra, A. Y. 2013. The water footprint of the EU for different diets. Ecological Indicators, 32, 1–8.

Wessels, K.R.; Brown, K.H. 2010. Estimating the global prevalence of zinc deficiency: Results based on zinc availability in national food supplies and prevalence of stunting. PlosOne. https://doi.org/10.1371/journal.pone.0050568

Westhoek H.; Lesschen J.P.; Leip A.; Rood T.; Wagner S.; De Marco A.; Murphy-Bokern, D.; Pallière C.; Howard C.M.; Oenema O.; Sutton, M.A. 2015. Nitrogen on the Table: The influence of food choices on nitrogen emissions and the European environment. (European Nitrogen

Assessment Special Report on Nitrogen and Food.) Centre for Ecology and Hydrology, Edinburgh, UK.

Westhoek, H.; Rood, T.; van den Berg, M.; Janse, J.; Nijdam, D.; Reudink, M.; Woltjer, G. B. 2011. The protein puzzle: the consumption and production of meat, dairy and fish in the European Union (No. 500166001). Netherlands Environmental Assessment Agency. URL: http://library.wur.nl/WebQuery/wurpubs/406619

World Cancer Research Fund, 2007. Food, Nutrition, Physical Activity, and the Prevention of Cancer: a Global Perspective. Washington DC. USA

World Health Organisation. 2003. Diet, nutrition and the prevention of chronic diseases.

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973

Disclaimer

The information presented here has been thoroughly researched and is believed to be accurate and correct. However, the authors cannot be held legally responsible for any errors. There are no warranties, expressed or implied, made with respect to the information provided. The authors will not be liable for any direct, indirect, special, incidental or consequential damages arising out of the use or inability to use the content of this publication.

Copyright

Citation

Please cite this report as follows: Styles, D., March, M., Sheeran, S., Williams, M. (2018). Report on Life Cycle Assessment Methodology for Assessing the Environmental Sustainability of Legume Value Chains. Deliverable 5.1 for the EU-H2020 funded project, '*TRansition paths to sUstainable legume-based systems in Europe*' (*TRUE),* under Grant Agreement Number 727973. Available online at: www.true-project.eu. DOI 10.13140/RG.2.2.34385.43367

ANNEX I: Case study farm data requirements

These are the data required, preferably at enterprise level (but could also be at field level for specific cropping sequences), to undertake economic and LCA modelling of Case Studies.
Ideally case study partners could provide historic data before (baseline) and after incorporation of legumes so that a before and after comparison of environmental footprints and economics can be made to elicit net legume effects at rotation level (capturing interactions, break-crop effects, etc) – see example for modified biogas-energy-crop rotations at the end of this document.

Cropping systems

- Crop varieties grown
- Areas (ha) under different crops/uses
- Rotation sequence (e.g. multi-year cropping plan)
- Yields for all crops (tonnes/ha, specify fresh matter or dry matter)
- Important crop quality parameters (water and nutrient content etc.)
- Crop use/marketing channel
- Inventory of main field operations for each crop (ploughing, tilling, fertilising, sowing…)
- Seed input (kg/ha)
- Organic fertiliser application rate and type
- NPK and lime application at crop (kg/ha) or enterprise (kg/yr) level, and specific types of fertiliser (e.g. urea-N, ammonium-nitrate-N, etc)
- If available, estimate of N delivery for following crop from legumes (kg/ha)*
- Agrochemical application at crop or enterprise level
- Diesel/electricity/fuel consumption at enterprise level
- Labour inputs
- Prices for all inputs and outputs
- Information on (crop) price variability and yield variability for all crops considered

*If data such as this are not available, we can infer from "before" and "after" rotations

Animal (& cropping) systems

- Area under different crops/uses (including grazing, cut and grazed, woodland)?
- Rotation sequence (e.g. multi-year cropping plan)
- Yields for all crops (tonnes/ha, specifying fresh matter or dry matter)
- Important crop quality parameters (water and nutrient content etc.)
- Crop use/marketing channel

- Tonnage of crops sold (need feed grown, used and sold)
- Dry Matter(DM) percentages at harvest for all crops (DM at feeding as well if possible)
- Inventory of main field operations for each crop (ploughing, tilling, fertilising, sowing…)
- Animal numbers by cohort (age groups; e.g. 0-6 month; 6-12 month, etc)
- Annual numbers and ages of animals born or bought in to farm, and sold from farm, lost or dying
- Average live weight of each cohort
- Replacement rate and Involuntary culling rate
- Avg. Calving Interval (for dairy) and Calving pattern (AYR or Block Spring or Autumn)
- Type of system: Organic or conventional
- Ration/Diet details for each of the animal groups (if they differ) – at least % energy intake as grass/concentrate/other feeds…
- Animal productivity (growth rates, milk production per animal per day/yr, final body weights)
- Enterprise productivity (kg live weight or kg milk exported from farm – ideally include milk fat and protein content details)
- Type of animal housing (slatted floor, solid floor, straw bedding, etc)
- Days/yr animals housed and days/yr animals grazed
- Type of manure management system (slurry tank, slurry tank covered, lagoon, anaerobic digestion, farm yard manure, *etc*)
- Manure application details: rate (tonnes/ha), method of application (solid manure, incorporated, broadcast, shallow injection, etc), time of year applied, to which crop
- Animal feed brought in to the farm (quantity by type), nutrient content
- Seed input (kg/ha)
- NPK and lime application at crop (kg/ha) or enterprise (kg/yr) level, and specific types of fertiliser (e.g. urea-N, ammonium-nitrate-N, *etc*)
- Agrochemical application at crop or enterprise level
- Diesel/electricity/fuel consumption at enterprise level
- Labour inputs (including unpaid labour)
- Prices for all inputs and outputs
- Information on (crop) price variability and yield variability for all crops considered

If before and after data are not available at enterprise or field level, then estimated effects of legume integration on fertiliser application rates and net productivity will be very important. Can these be derived by comparing case study legume rotations with regional average yields and fertiliser application rates?

This Project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 727973