TRansition paths to sUstainable legume-based systems in Europe

Web-based tool for legume systems

Work Package: 8

Deliverable (D): D8.4

Lead Author and Institution:
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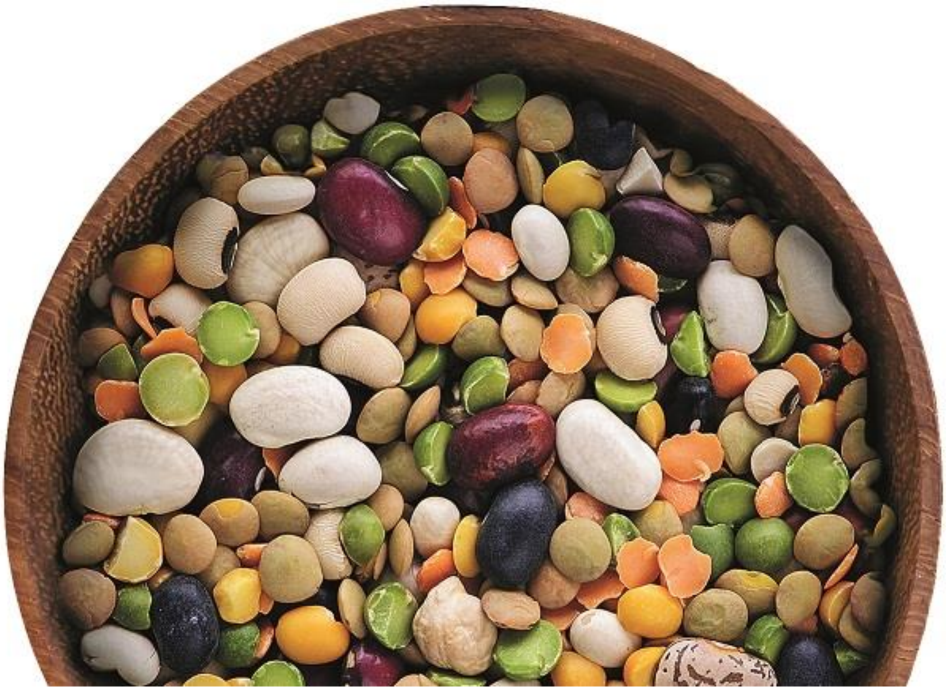

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Deliverable Description & Contributors

- **Due date**: 30th September 2021
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- **Work package**: Transition Pathways (WP8)
- **Work package leader**: Marko Debeljak (JSI)
- **Deliverable title**: Web-based tool for legume systems
- **Nature of Deliverable**: DEM/OTHER
- **Dissemination level**: Public (PU)

- **Deliverable description:** The series of sustainability assessment models and their integrated model reported in the Deliverables D8.2 and D8.3 are inbuilt into a web-based decision support system (DSS) called Pathfinder. It provides assessment and analysis of the sustainability performance of the entire agri-food chain and its links. This Deliverable introduces the conceptual structure of the DSS, provides a description of the key modules and how they have been developed and gives details on the implementation of the web-based decision support tool. Pathfinder is available at http://pathfinder.ijs.si.

- **Contributors**

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  - Fanny Tran, Pietro Iannetta (JHI)

- **Keywords:** Decision support system; Web-application; Sustainability assessment; Sustainability modelling; Agri-food chain.

Contents

1. Introduction

This Deliverable provides an overview of the web-based decision support system (DSS) for legume agri-food chains called 'Pathfinder', developed to help producers, farm advisors, policy-makers, researchers, students, stakeholders and other end-users to assess and model the sustainability of legume-based farming systems and other links of the chain and the agri-food chain as a whole. The overview includes development and implementation of the system modules into a web-based decision support tool, including data storage and user interface components. Additionally, this Deliverable reports on the hosting servers and web-access to Pathfinder.

During the previous work in Work Package (WP) 8, a set of qualitative multi-criteria models were developed to assess different sustainability aspects (D8.2) and linked into integrated model for assessment and modelling sustainability (D8.3). Once the models were developed, the conceptual structure of DSS, which consists of different modules was developed. These interlinked models allow end-users to enter data into a DSS, providing sustainability assessment, in top-down and bottom-up analysis. All of the modules are available through a single user interface that was designed and developed for efficient and intuitive interaction with the end-users. These three main modules are the core of the web-based DSS called 'Pathfinder'. Additionally, the system provides user management, printing reports and information about privacy policy and terms of use.

To provide a detailed overview of each module, their interactions and visualisation, this Deliverable first introduces the general conceptual structure of the DSS, then gives technical details (software packages) about the implementation and use for each module, followed by the rationale behind the design of the graphical user interface. The Deliverable concludes with a specification of the deployment and web access.

2. The conceptual structure of the web-based decision support system

The conceptual structure of the web-based DSS shows its modules and how they are organised and interconnected in the DSS Pathfinder. In particular, the DSS consists of three conceptual modules to: (i) enter data describing the current state of the assessed link of the agri-food chain (data entry module); (ii) assess the current level of sustainability performance (sustainability assessment module); and (iii) analyse the sustainability performance when the changes to the current set of input data is introduced (sustainability analysis module).

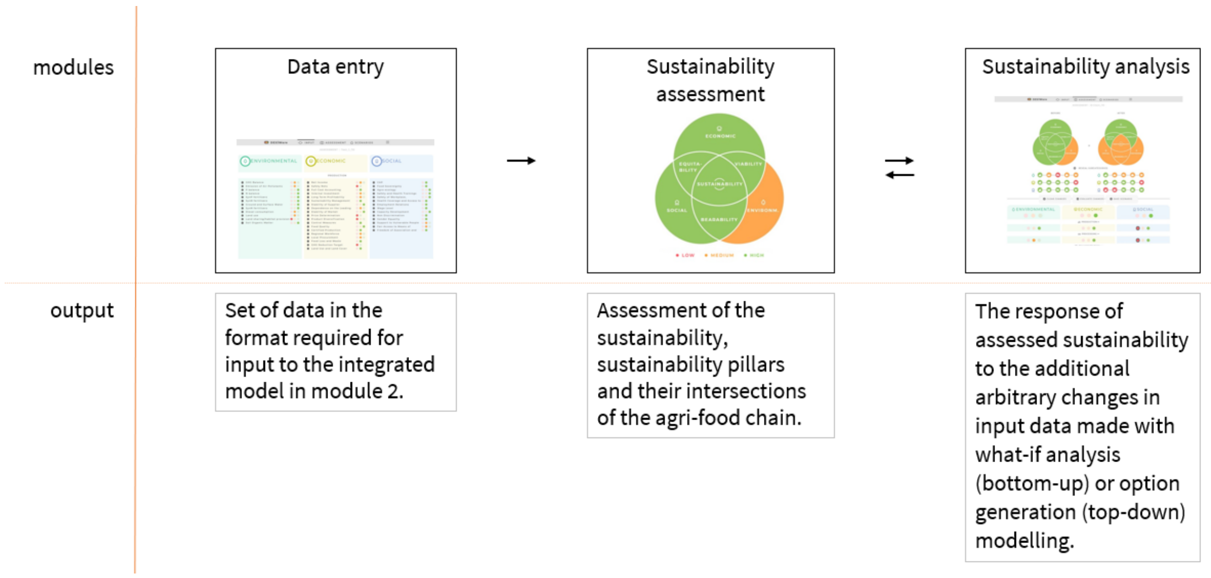

Figure 1. Conceptual structure of Pathfinder. The DSS is composed of three modules *Data entry*, *Sustainability assessment*, and S*ustainability analysis*. The arrows between modules show the data and information flow between modules.

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2.1 Data entry module

The *data entry* module is used to enter the collected data into the DSS. The data are entered separately for the three pillars of sustainability of the agri-food chain (environmental, social and economic), which are further subdivided into five subcategories representing the links of the agri-food chain (from agricultural production to the consumer). The individual input data fields correspond to the inputs in the sustainability assessment models for each pillar of the link in the agri-food chain (Figure 2). Details of the 15 sustainability assessment models (5 links with 3 pillars) and the corresponding input attributes are described in Deliverable D8.2.

Figure 2. The data entry module is divided into three categories (sustainability pillars), which are further subdivided into five links of the agri-food chain. Once the data are inserted the data entry fields are marked with a black dot and their values are indicated by red, orange and green colour, corresponding to their qualitative values from low to high.

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The data entry is facilitated by a pop-up window containing a detailed description of the selected input attribute and its values (Figure 3), as described in the data factsheets in the appendices of D8.2. In addition, the completeness of data entry for all required input data is displayed at the top of the screen (black dots mean data entered, blank dots mean data not yet entered or missing data).

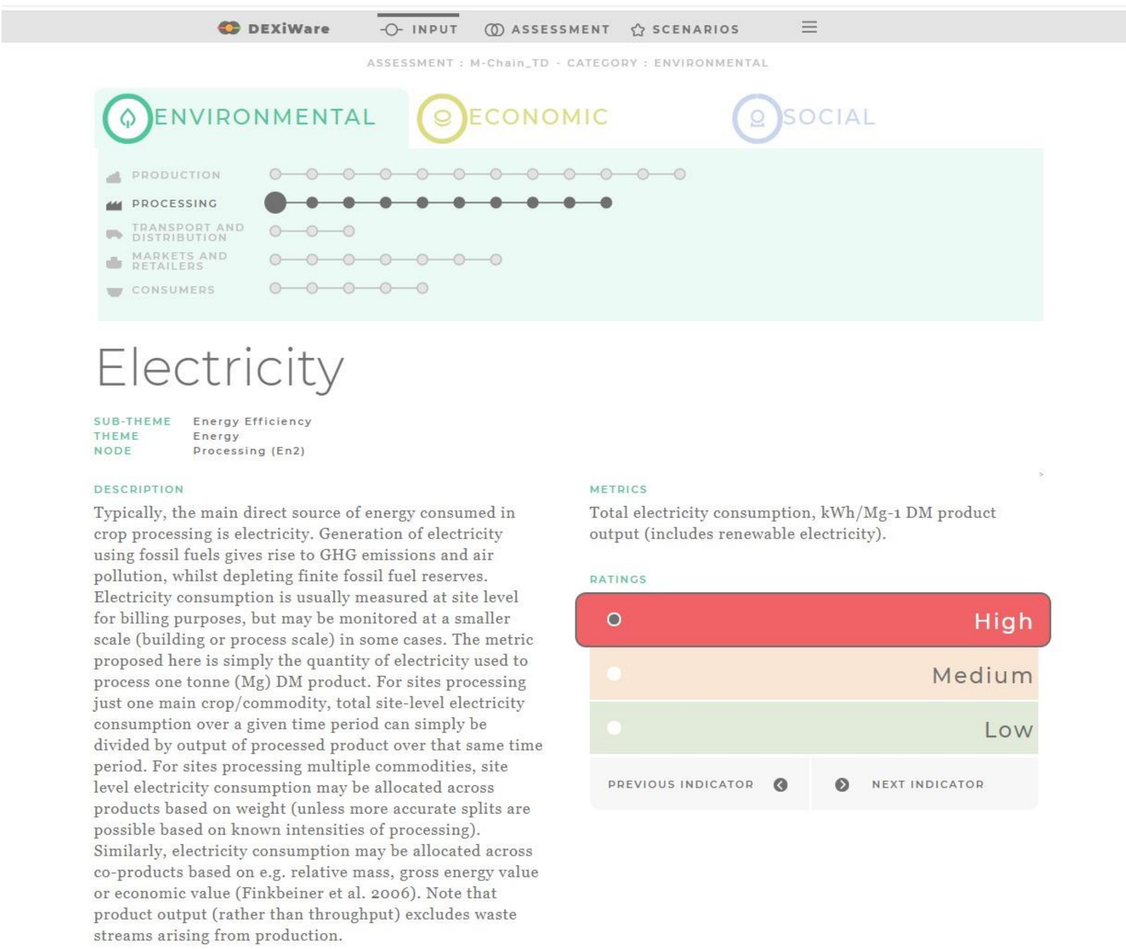

Figure 3. Data entry is facilitated by a detailed description of the selected input attribute. The selected value is shown in bold.

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2.2 Sustainability assessment module

The *Assessment of sustainability* is the main goal of the second DSS module. It provides the sustainability assessments at all three levels of the integrated model described in the Deliverable D8.3. The overall sustainability of the chain (Tier 3) is the integration of the outputs of the sustainability assessment models at Tier 2 that link the outputs from 15 sustainability models at Tier 1. The outputs of the assessment models at all three levels are given on a scale of three possible qualitative values presented in green (high sustainability level), orange (medium sustainability level) and red (low sustainability level) colour (Figure 4). The grey colour indicates assessments that have not been performed due to the missing input data (not present in Figure 4).

The assessment module has a very central position in the structure and functioning of the DSS. It receives all required data from the data entry module and all the necessary instructions to perform what-if (bottom-up) or option generation (top-down) modelling tasks from the analysis module. It also sends information about the assessment and modelling results back to the analysis module to support the iterative modelling process used to achieve arbitrarily chosen sustainability goals. Its central part is the integrated model developed in D8.3, which performs all the assessment and modelling functions of the DSS.

Figure 4. Sustainability assessment of the agri-food chain and its links. Based on the data provided by the data entry module the integrated model assesses different aspects of sustainability at all three levels (Tier1, Tier2, Tier 3) of the agri-food chain.

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2.3 Sustainability analysis module

The sustainability analysis module was developed to investigate and quantify the impact that a change in input data can have on sustainability performance. The module addresses changes caused by: i) end-users (bottom-up analysis); or ii) the modelling software of this module according to the desired level of sustainability performance set by the end-user.

Figure 5. The results of the sustainability analysis module are presented as the difference between the sustainability assessment results based on the original data, marked in the figure labelled 'BEFORE', and: i) the sustainability assessment results based on the input data modified by the end-user (bottom-up); or ii) the input data modified by the modelling software according to the desired level of the sustainability performance of the agri-food chain and its parts (top-down), either marked in the figure labelled 'AFTER'.

If the changes are made by the end-users, then this module performs what-if analysis of the sustainability performance under a modified set of input data. In addition, it also provides the information about the differences in effects of modified input data compared to the original input data (Figure 5). In case that the end-user wishes to explore options (*e.g.,* different combinations of input data) that would lead to the desired sustainability performance of the whole chain or its parts, this module software explores ways to achieve the desired performance and provides the necessary changes to the input data. The suggested changes can be further explored and used in the development of a management plan to improve the sustainability of the assessed agri-food chain.

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3. Implementation

3.1 Software architecture

The DSS Pathfinder is developed as a web-based tool implemented in a server-client architecture, allowing interaction between DSS modules through an application programmable interface (API). In addition, the server-side contains a database that stores important information about the end-users and the input data. For assessment and analysis, the web-based tool uses a custom DEX library (Figure 6). The client-side of the architecture includes a graphical user interface (GUI) that guides the workflow through the modules and facilitates interaction between the end-users and the web-based DSS.

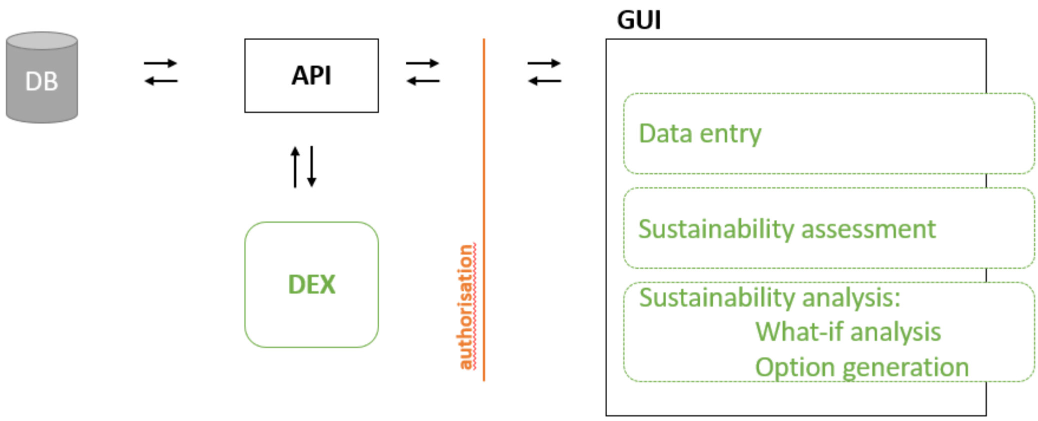

Figure 6. A conceptual diagram of the software architecture for web-based decision support tool (DB-Database, API - application programmable interface, GUI - graphical user interface).

Table 1. Specification of technologies, execution platforms and programming languages used for implementation of the web-based decision support tool (DB-Database, API - application programmable interface, DEX - library, GUI - graphical user interface).

Component	Platform	Technology	Language
DP	Server (Linux)	PostgreSQL, Sequelize	SQL, Javascript
API	Server (Linux)	Node.js, Express	Javascript
DEX	Server (Linux)	Custom	Java, Javascript
Authorisation	Server (Linux)	Node.js, Passport.js	Javascript
GUI	Client (Web browser)	Angular	Javascript

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The underlying methods used to implement the web-based tool and its components are summarised in Table 1, while Figure 7 provides details of the structure of the Pathfinder DSS database.

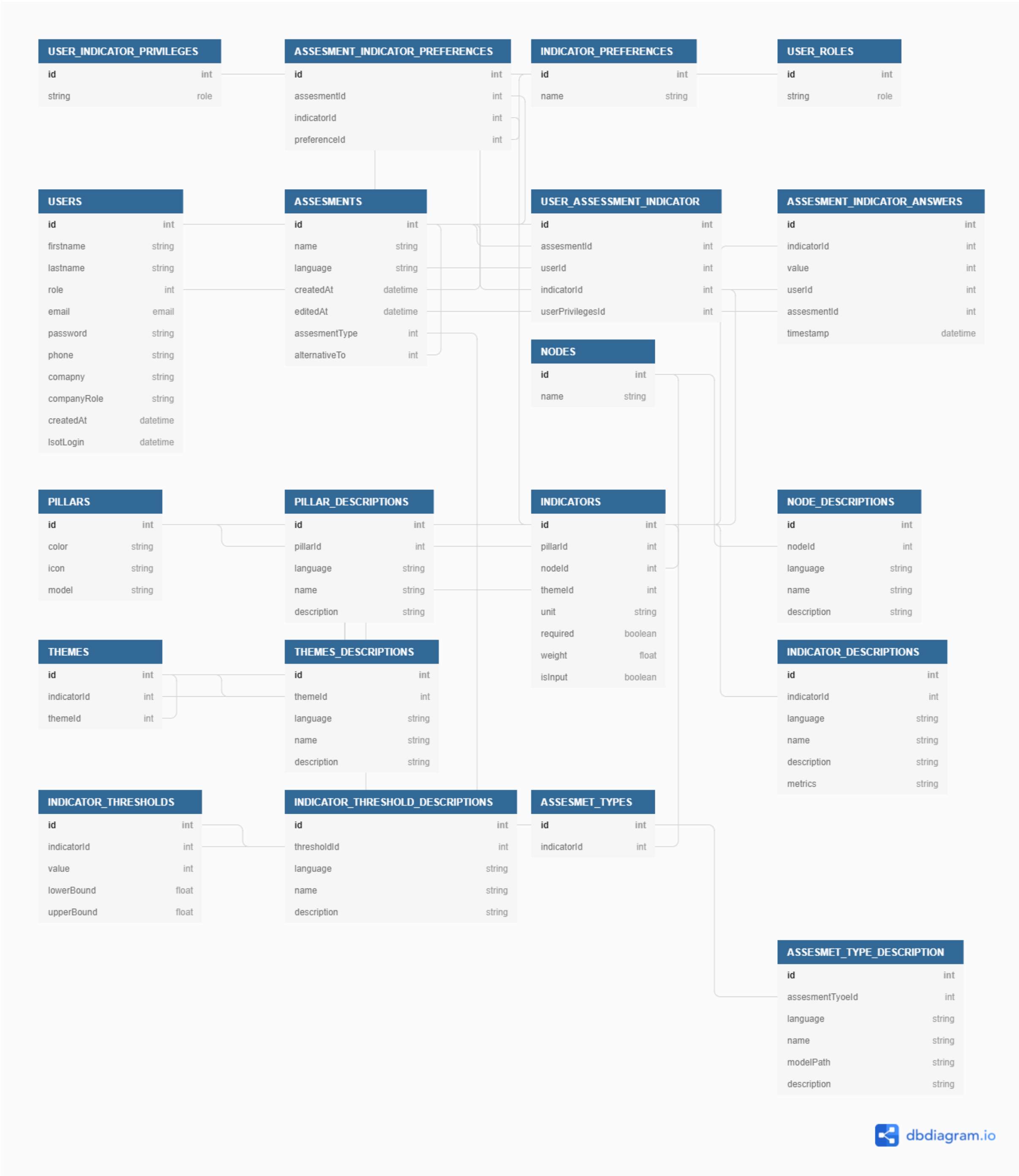

Figure 7. Database structure of the Pathfinder decision support system.

3.2 Graphical User Interface & Human-Computer Interaction

Pathfinder is a DSS for assessing and modelling the sustainability of legume-based agri-food chains and their links. Sustainability is treated as: i) an intersection of three sustainability pillars (environmental, social and economic) and their pairwise interactions (equitability, bearability and viability) (Tier 3); ii) three individual sustainability pillars (Tier 2); and iii) sustainability pillars of the individual links (production, processing, transport and distribution, markets and retailers, and consumers) of the agri-food chain (Tier 1). While the individual decision models (D8.2) and the integrated model (D8.3) have been developed, validated and reported, this section focuses on the needs and expectations of end-users that should be considered in the development of an intuitive and user-friendly web-based interface.

The first step in developing the graphical user interface (GUI) was to identify the end-users of Pathfinder. Based on the brief descriptions of end-users in D8.2 and D8.3, we categorised them into the following three groups: i) public authorities and farm advisors; ii) consultancy companies; and iii) researchers. While the motivation for using the Pathfinder varies between end-users (*e.g.* development of sustainability strategies, improvement of sustainability performance, consultancy on sustainable development, research activities), the required functionality of the Pathfinder remains the same for all types of users. They all have opportunity to provide input data through a data input interface, they need to receive the results of the sustainability assessment or modelling in a clearly readable and easily understandable form, and their active participation in the what-if analysis or generation of options needs to be informative, flexible and intuitive. Given the large amount of input data required plus the large number of assessments and modelling results, the graphical design of the interface for presenting the results is standardised for all functional features of the Pathfinder. Thus, the process of data entry is the same for all input data, and the presentation of sustainability assessment results is kept the same for all links at Tier 1. The fulfilment of the individual sustainability pillars is also presented in the same graphic design. Even at the top level, the results are presented with the same sustainability rose design, regardless of whether they are the results of the sustainability assessment, the results of the what-if analysis (bottom-up) or the results of the option generation (to-down) modelling. Furthermore, the colours and their meanings are the same throughout the user interface.

Some input data or results could be subject of privacy issues. This was an additional requirement considered in the development of the GUI. We solved it by the development of the user management feature of the Pathfinder. It offers the possibility to assign different operational rights to different types of end-users. In addition to having access to all of Pathfinder's functional features, some users can also be given rights to only some of them. In particular, those who own the assessment (and thus the data) have access to all features by default, while the so-called contributors have access to all or only some parts of the data entry sections only (*e.g.,* only enter data for the selected link), while viewers can only see the results (*e.g.,* read-only rights) but cannot manipulate or enter data or perform analysis functions. Data protection issues are thus mainly addressed by assigning end-users to one of the operational rights levels. It is worth noting that the operational rights do not have an exclusion relationship with the Pathfinder user types. Table 2 summarises the user types and the different levels of operational rights that can be assigned to each Pathfinder user type.

Table 2. Types of Pathfinder users and the levels of Pathifinder operational rights

User types and roles		Data entry	Assessment	Analysis	Reporting	User management
User types	**Public authorities, farm advisors**	Yes	Yes	Yes	Yes	Yes
	Consultancy companies	Yes	Yes	Yes	Yes	Yes
	Researchers	Yes	Yes	Yes	Yes	Yes
Operational rights	**Assessment owner**	Read and write	Read and write	Read and write	Read and write	Yes
	Data contributor	Read and write	No	No	No	No
	Results viewer	Read-only	Read-only	Read-only	Read-only	No

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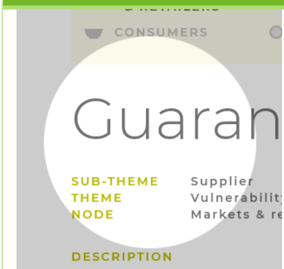
The next step in the development of the GUI was the selection of typography, the definition of a visual hierarchy with the selection of appropriate colours, the positioning of the GUI elements on the screen area and the selection of their size, design of custom icons, *etc.* Some of the steps are visually represented and explained in Table 3.

The main objective of this graphical design subsection was to enable the end user to:

- understand the agri-food chain sustainability assessment through clear and well-structured and visualised results;
- visually highlight the information exchange with the end user through colourful infographics;
- perform analysis (what-if, option generation) for the agri-food chain with interactive elements that allow comparisons of the analysed scenarios and help to select the most optimal scenario for further implementation; and,
- have confidence in the accepted changes that will lead them to the desired level of sustainability performance through automatically generated reports.

Table 3: Some of the implemented design solutions for efficient visual communication of the Pathifinder with the end-user.

<table>
<tr><th colspan="4">Data entry</th></tr>
<tr>
<td>
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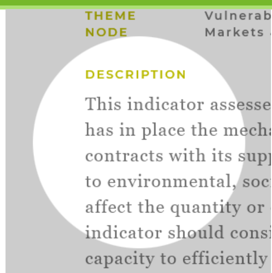
<td>
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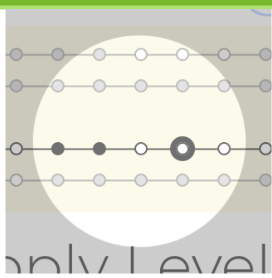
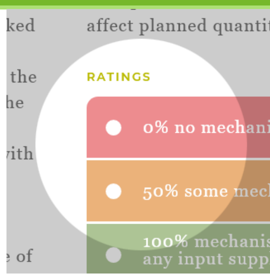
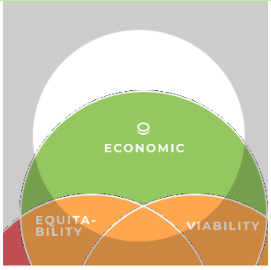
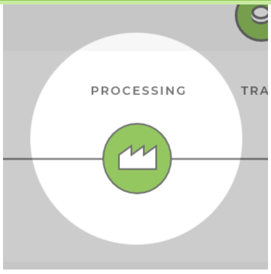
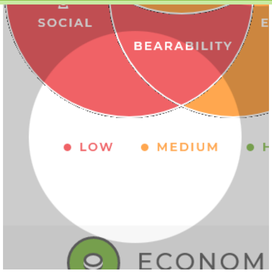
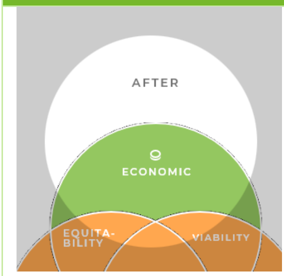
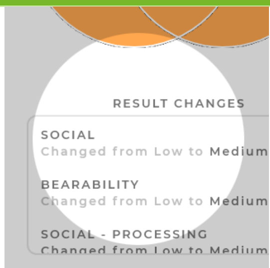
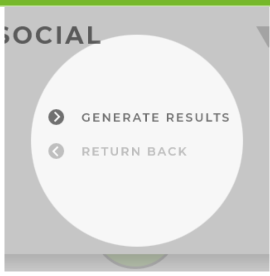
<td></td>
<td>
</td>
</tr>
<tr>
<td>A clear visual hierarchy with large contrasts between categories draws the user's attention to the most important information.</td>
<td>The improved readability of the text with reduced line width and increased line spacing makes it possible to read the descriptions comfortably.</td>
<td>The completeness of the data entry for all required input data gives the user the orientation about the input data.</td>
<td>Bright colours, clear descriptions and consistent position allow the user to easily complete each step of the process.</td>
</tr>
</table>

Sustainability assessment			
			
The simple visual representation of complex results with coloured diagrams enables the user to quickly grasp the data.	Detailed analysis of specific aspects with colored icons leads the user to insights of the analyzed processes in the value-chain.	Clear explanations of the charts with provided additional information ensures correct interpretation of the results.	Simple ways of testing different scenarios (bottom-up or top-down) guides the user through additional analysis.
Sustainability analysis			
			
Effortless insights of the consequences that changes of input data have on top-down or bottom-up analysis.	Exhaustive textual description of changes in top-down or bottom-up analysis.	Automatic generation of all the alternative combinations of input data that lead to the desired result of the top-down analysis.	Easy way to save scenarios with a save button under each chart for its later comparisons with the result of other assessments or analyses.

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4. Deployment & Access

The Pathfinder is hosted on a dedicated virtual machine on JSI's premises in Ljubljana, Slovenia. To ensure enough processing power to support Pathfinder's complex analytical options the virtual Ubuntu Linux server is equipped with 10GB of memory, 8 processing cores and 60GB hard-drive.

The focal point for the development team was JSI's GitLab where the source code is hosted and organized in separate branches so that the generic part of the tool can be reused in similar contexts such as the TRUE project. To ensure smooth deployment of changes to the tool, three environments have been defined and set up:

- **development environment:** used by developers during development of new features on their machines connected to a local database;
- **staging environment:** used to test new features by the whole team and external stakeholders when needed connected to a separate database and available at http://pathfinder.ijs.si/true/stag;
- **production environment:** used as the actual working version of Pathfinder by users, connected to the main database and available at http://pathfinder.ijs.si/true

Backups of the production database are automatically produced daily and stored in the cloud on a physically separate machine to avoid loss of data.

Access to Pathfinder is given upon request. Users are not allowed to register themselves, although such functionality is implemented and can be enabled anytime. A brief presentation of Pathfinder as a tool and contact data to request access are available at http://pathfinder.ijs.si. Once a user is granted access with a username and a password, the user can invite additional collaborators to the tool to help with data gathering and performing analysis. This is done via the user management interface of Pathfinder (Figure 8).

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Figure 8. The user management functionality of Pathfinder enables users to invite collaborators to help gather all the required data. Access can be fine-tuned for each item (indicator, pillar, node) and includes permissions such as read-only or edit.

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5. Conclusions

Sustainability must almost inevitably be incorporated into all management activities and human behaviours. In some well-specified cases, sustainability can be well defined and quantified (*e.g.,* for a particular company or production, a particular product). However, when diverse and complex systems need to be assessed, sustainability analysis faces the problem of using appropriate metrics and choosing reliable integration methods that provide information on sustainability performance at the system level.

These shortcomings are, in a sense, a consequence of the limitations of the sustainability analysis currently in use. In most cases, they focus on the individual elements of the system under study rather than on the system as a whole. Moreover, most analyses only provide a sustainability (or more likely environmental impact) assessment at a point in time. That is, such assessments normally place sustainability analysis in a passive position, as they normally only provide information on the current sustainability performance of the systems under study.

We have shown that the qualitative decision modelling chosen for the development of Pathfinder is an appropriate method for an objective sustainability assessment and analysis of the complex systems and their elements. (*e.g.,* the agri-food chain and its links). Our approach, which also integrates a partial sustainability assessment, goes beyond most sustainability assessment methods that only offer partial assessments. For example, Pathfinder offers a sustainability assessment of the sustainability pillars and the entire agri-food chain.

Unfortunately, assessment analyses cannot provide information on how to improve the level of assessed sustainability performance and required sustainability modelling methods are very rare. However, through the use of advanced computer technologies, we have developed the sustainability analysis module which provides a what-if analysis of sustainability and enables the modelling of sustainability.

In the what-if analysis, the user examines how changes in input data (*e.g.,* increase in energy prices, changes in transport methods, change in consumer habits, *etc*.) affect the sustainability

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performance of the assessed agri-food chain and its links (bottom-up approach). The user can also use this analysis feature to identify the most critical attributes that could jeopardise the sustainability achieved. The what-if function thus allows the user to determine how to improve or maintain the sustainability level.

The complexity of the system (*e.g.,* the agri-food chain) for which Pathfinder was developed is very high, so finding the most necessary changes in the input data through the bottom-up what-if analysis requires a high level of expertise. Unfortunately, with the very large number of input attributes, the number of possible changes in the input data is almost unmanageable. To solve this problem, we have introduced in this module a sustainability modelling function that operates on a top-down principle. Once the user specifies the target sustainability level at the level of the whole agri-food chain, Pathfinder provides a set of necessary changes of the input data that can be used to achieve these goals.

These new functionalities of sustainability assessment and analysis would not have been possible without a transdisciplinary research approach. Indeed, we have succeeded in complementing agricultural sciences with the scientific fields of ecological modelling, decision analysis, informatics and computer sciences. The results presented in this Deliverable confirm that transdisciplinary research can significantly support the transition to a sustainable society.

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Graphical representation of the user interface of Pathfinder present in this document originates either from the design process or from screenshots of the actual tool at the time of writing. This may change as the tool evolves or is updated for maintenance.

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Also available online at: www.true-project.eu.

Appendix I: Background to the TRUE project

TRUE Project Executive Summary

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 sustainabilit*y' – '*environment*', '*economics'* and '*society'* - may be best resolved.

TRUE realises a genuine 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 facilitate 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 & 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 by greenhouse gas specialists at Trinity College Dublin (Ireland; in close partnership with Life Cycle Analysis 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), respectively. 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 thresholds (or goals) to which each SDI should aim. Data from the *foundation WPs* (1-4), to and 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.

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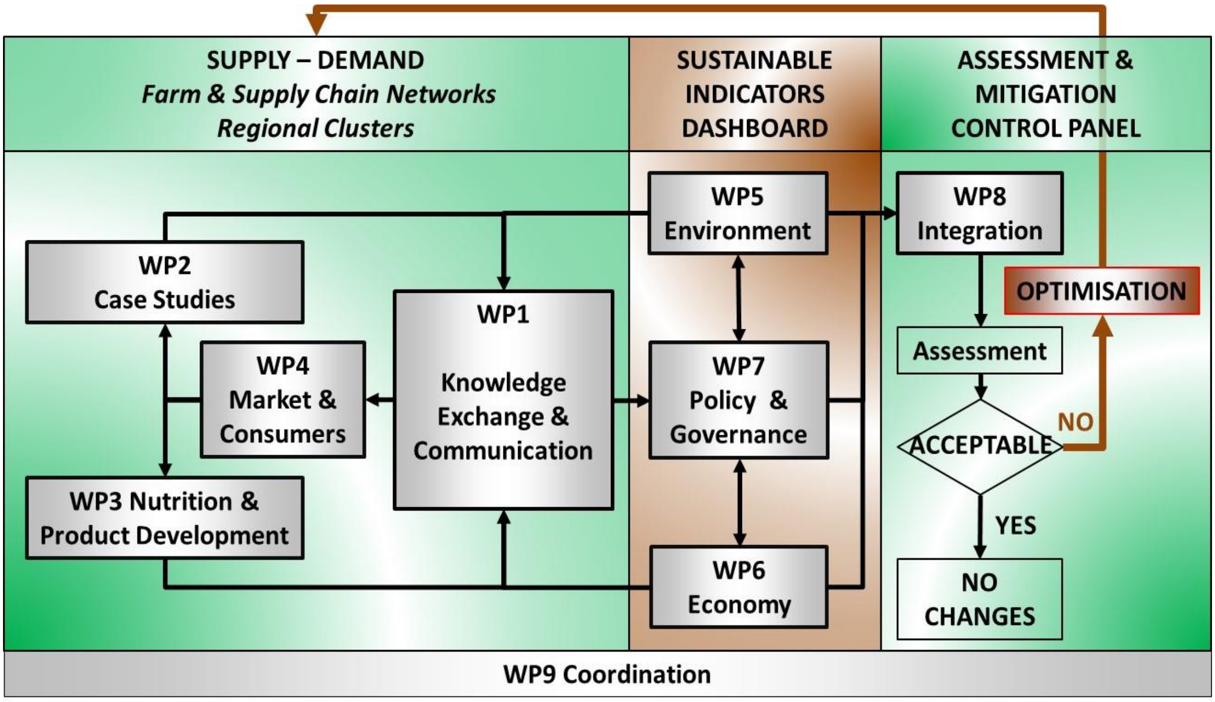
Work Package Structure

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) (Figure 1).



Work package structure and flow of information and knowledge between work packages.

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Project Partners

Nº.	Participant organisation name (and acronym)	Country	Organisation Type
1 (C*)	The James Hutton Institute (JHI)	UK	RTO
2	Coventry University (CU)	UK	University
3	Stockbridge Technology Centre (STC)	UK	SME
4	Scotland's Rural College (SRUC)	UK	HEI
5	Kenya Forestry Research Institute (KEFRI)	Kenya	RTO
6	Universidade Catolica Portuguesa (UCP)	Portugal	University
7	Universitaet Hohenheim (UHOH)	Germany	University
8	Agricultural University of Athens (AUA)	Greece	University
9	IFAU APS (IFAU)	Denmark	SME
10	Regionalna Razvojna Agencija Medimurje (REDEA)	Croatia	Development Agency
11	Bangor University (BU)	UK	University
12	Trinity College Dublin (TCD)	Ireland	University
13	Processors and Growers Research Organisation (PGRO)	UK	SME
14	Institut Jozef Stefan (JSI)	Slovenia	HEI
15	IGV Institut Fur Getreideverarbeitung Gmbh (IGV)	Germany	Commercial SME
16	ESSRG Kft (ESSRG)	Hungary	SME
17	Agri Kulti Kft (AK)	Hungary	SME
18	Alfred-Wegener-Institut (AWI)	Germany	RTO
19	Slow Food Deutschland e.V. (SF)	Germany	Social Enterprise
20	Arbikie Distilling Ltd (ADL)	UK	SME
21	Agriculture And Food Development Authority (TEAG)	Ireland	RTO
22	Sociedade Agrícola do Freixo do Meio, Lda (FDM)	Portugal	SME
23	Eurest -Sociedade Europeia De Restaurantes Lda (EUR)	Portugal	Commercial Enterprise
24	Solintagro SL (SOL)	Spain	SME
25	Public Institution for Development of Međimurje REDEA (PIRED)	Croatia	Development Agency

*Coordinating institution

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Objectives

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 & 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*

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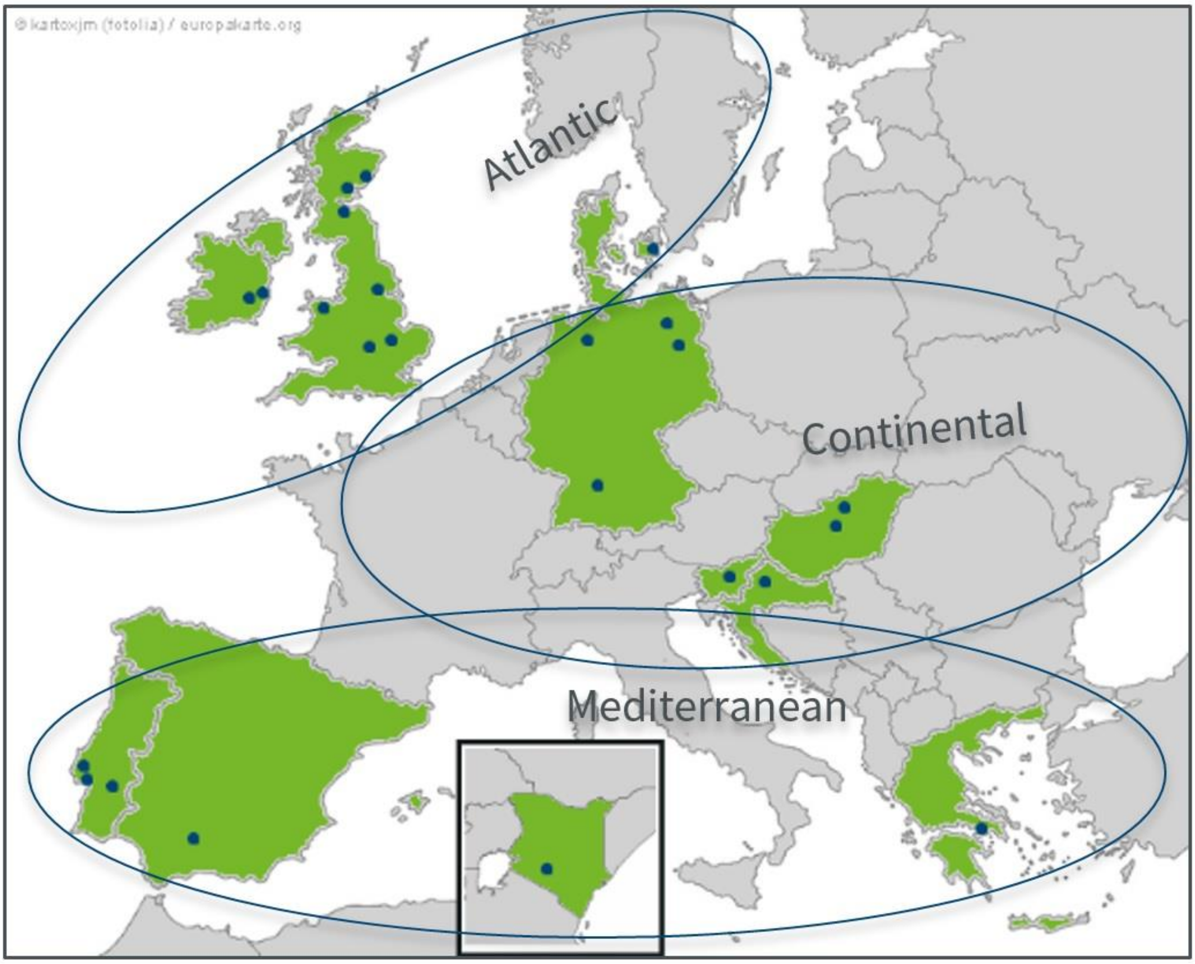
Legume Innovation Networks & Case Studies

Knowledge Exchange and Communication (WP1) events include three TRUE European Legume Innovation Networks (ELINs) and these engage multi-stakeholders in a series of focused workshops. The ELINs span three major pedoclimatic regions of Europe, illustrated above within the ellipsoids for Continental, Mediterranean and Atlantic zones (Figure 2).



Three TRUE European Legume Innovation Networks (ELINs).

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