Final Report

For more information and guidance on completion and submission of the report contact the Euphresco Call Secretariat (bgiovani@euphresco.net).

Project title
Assessment and prioritisation of pathways

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2. Short project report

2.1 Executive Summary

There is an increasing interest, both regulatory and scientific, in the pathways used by plant pests and diseases to spread to, and establish in, new locations across the globe. A pathway can be defined as ‘any means that allows entry and spread of a pest’ (IPPC 2018), covering both natural and human driven processes. With world trade continually evolving and new trade links between countries being formed on a regular basis, new pathways are being created and emerging pathways increase in importance. Biosecurity measures such as the application of quarantine and implementing trade restrictions are usually based on species specific risk assessments of known pests and diseases. However, the larger challenge comes from emerging pests and diseases, which often are not considered a problem in their native ranges due to the coevolution of plant defences and natural control by predatory and parasitic species. In a more connected world, pathways assessments can help protect against new and emerging pest species by identifying the generic risks associated with a pathway.

The project is focussed on initiating a network of practitioners of pathway analyses for plant health. As a starting point for the network, the project partners considered addressing 4 objectives:

1. Identify current systems and methodologies used to assess new and emerging horticultural trade pathways
2. Identify knowledge gaps regarding current industry practices in exporting countries
3. Develop proposals to overcome existing difficulties in assessing pathways
4. Provide a report on options for the systematic evaluation and prioritisation of pathways

The project held a workshop in Angers, France, made up of representatives of the five partner organisations from Europe and North America and invited contributors from the French agricultural research and international cooperation organization (CIRAD) and the European and Mediterranean Plant Protection Organization (EPPO). The European partners attended in person while the North American partners attended by video conference. Each partner organisation presented their work on pathways assessment, and discussions were held on the similarities and differences between the approaches of each of the partners. This was followed up with a videoconference to further develop and report on the ideas raised at the workshop. The project partners identified a series of knowledge gaps which would need addressing to allow pathways assessments to be more widely performed, along with suggestions for approaches to filling these knowledge gaps.

2.2 Project aims

The upcoming replacement EU "Plant Health Law" (Regulation (EU) 2016/2031) puts an increased emphasis on pathways for introduction of plant pests and pathogens compared to the current legislation. The aim of a pathway assessment is to identify the inherent likelihood of a pathway for causing pest introduction separate from the known specific risk of individual pest or disease species to cause damage. To achieve this, the pathways approach to plant health requires different methodologies and sources of information to the current species focussed PRA methods. In particular it requires improved information on transport history and nature of trade in plants and plant products, for which cooperation between trading nations in collating this information is key.

The goal of the project is to begin building an international network to allow cooperation in performing pathway analysis for the introduction of plant pests and diseases.

The project had 4 objectives:

1. Identify current systems and methodologies used to assess new and emerging horticultural trade pathways
2. Identify knowledge gaps regarding current industry practices in exporting countries
3. Develop proposals to overcome existing difficulties in assessing pathways
4. Provide a report on options for the systematic evaluation and prioritisation of pathways

2.3 Description of the main activities

Workshop

A two-day workshop for project partners was run by ANSES on the 18th/19th October 2017. European partners attended in person at the ANSES offices in Angers, France. The US and Canadian partners participated by videoconference. Representatives from EPPO and CIRAD also attended the workshop.

Day 1: The workshop was focussed on recent work undertaken by the project partners on pathways assessment. Given the cross regulatory makeup of the project team (from government inspection agencies to research organisations) the presentations covered both developmental and operational aspects of pathways analysis. Items identified in the discussions included:

- Methods for pathway assessment
- Application of multicriteria analysis to identify riskiest pathways
- Modelling of entry and outbreak risks
- Lists of pest – commodity associations
- Identifying new and emerging pathways as they become established
- E-commerce as a new and poorly regulated pathway
- Biosecurity of shipments in transit
- Variability of pathway complexity
- Predictive modelling to inform on pathway assessments

Day 2: Started with a visit for the European project partners to the Headquarters of French seed producer Vilmorin in La Ménitré, where they heard about the internal industry procedures and processes that are applied in the seed trade. This included a tour of Vilmorin's quarantine facilities where they test seed shipments for pathogens. The nature of these tests is dependent on the phytosanitary legislation for the destination country, such that only the tests for quarantine pests or diseases in the destination country are carried out.

The afternoon session consisted of discussions of the issues identified on Day 1 and how they apply to the four objectives for the project. The project team began working on a prototype pathways framework to help identify and characterise the sources of uncertainty and complexity in a pathway. The project team identified the following significant knowledge gaps:

- Interceptions and understanding the amount of inspection effort that went into making those interceptions
- Commodity coding and improving the granularity for some commodities which can cover a large variety of host species
- Trade statistics and reconciling different sources of trade data. In particular, a lack of sources for identifying intra-EU trade and trade in Asia was identified as a significant barrier to identifying new and emerging trade pathways.

Follow-up Videoconference

The videoconference on the 16th February 2018 was held to allow the project partners to collaborate on pathway assessment uncertainty and complexity. Based on the six components of pathway assessment identified by Wilson *et al*. (2016) for their grain pathway, the project team put together lists of knowledge gaps and approaches to fill those gaps for each component. The six components considered are:

1. Point of origin
2. Production practices
3. Post-harvest treatment
4. Transport and storage
5. Border processes
6. End use in importing country

Systems and methodologies to assess new and emerging pathways

The approaches that the partners had recently taken towards pathways assessment are detailed in Annex I. This includes an outline of a system that Fera Science are developing to identify trade anomalies to identify changes in pathways for commodities, and a statistical model used to investigate the relationship between interceptions and country level environmental, social and economic indicators. The report describes the knowledge gained by CFIA from conducting commodity risk assessments (CRA) over the last 30 years. This includes the difficulties they have faced in obtaining the correct information to perform the CRA, the expectations on time to completion from industry who pay to initiate the CRA and measures put in place to expedite the process. The practices by USDA-APHIS closely align with those of CFIA, and the report expands on their use of qualitative, quantitative, semi-quantitative, and predictive modelling approaches to inform pathway analyses.

ANSES report on a study to assess the import pathways for fruit and vegetables to Réunion Island and rank them for risk for the fruit fly species considered to be the highest threat to the island. The study resulted in the development of an information system holding data collected from a range of databases, websites and publications, and a decision support system based on the PROMETHEE multi-criteria method which allows the border agency to adapt control to the risks of each pathway. ILVO describe the HarmVect tool which characterises pathway risk associated with the point-of-entry and point-of-appearance. This is achieved by guiding the user to identify each of the pathways which arthropods may use, and sub-dividing those pathways into segments to identify the information required by the tools for that segment of the pathway. This system allows the user to identify knowledge gaps and perform a comparison of relative risks for different pathways. However, at this point the uncertainties within the information used by the model are too great to make an accurate quantitative calculation of risk.

2.4 Main results

During the workshop held at ANSES in Angers, the project partners identified six pathway components for generic plant trade pathways, based on the conceptual diagram shown in Figure 1. Four of the pathway components exist in the pre-border space for the importing country or trading bloc, one involves the processes on the border at the point of entry into the importing country or trading bloc, and the final component represents the post-border processes within the importing country or trading bloc. The section below briefly outlines the knowledge gaps that have been identified for each component of the pathway during the discussions at the workshop and in the videoconference, and lists the approaches which could be used to address those gaps (see Annex II for more details).

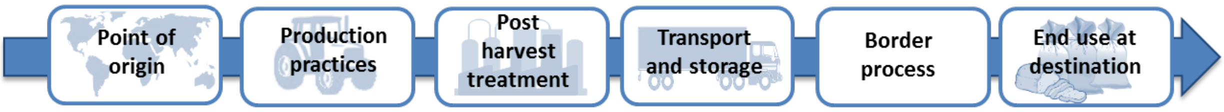

Figure 1. Conceptual pathway component diagram.

Knowledge Gaps

Point of Origin

- High variability in specificity of commodity codes used for assigning customs tariffs in the Harmonised System (HS) and Combined Nomenclature (CN) system.
- Risk of introduction of pests or diseases through packing materials may be higher than through the commodity itself
- Lack of clarity regarding the true country of origin, due to complex history of imports and exports, and ability to re-export
- Lack of information recorded with the commodity to identify the origin of the plants within countries of trading blocs like the EU.
- Pest presence in the country of origin
- Ability of a species transported to a new country outside of its natural range to become a pest
- Effect of the social and economic situation in the country of origin on the pre-border components of the pathway.

- Influence of socio-economic measures related to investment in infrastructure and regulation on the pathway risk for commodities.

Production Practices

- Different levels of pest management can be applied to the production of a commodity.
- Use of integrated pest management and conventional or organic production practices.
- How do risks differ between open field and greenhouse production.

Post-harvest Treatment

- Lack of understanding of what "best practice" for post-harvest management of a commodity means to each exporting country.
- What treatment, if any, is applied to wood and live plant commodities

Transport and Storage

- Levels of cross-contamination in storage and conveyances
- Use of controlled environments for storage and transport
- Pest survival and multiplication in transport

Border Process

- Inspection priorities and sampling processes
- Ability to detect and detection methods
- Amount of illegal or accidental importation

End Use at Destination

- Risk of diversion of intended use
- In-country storage and transport for importing country (spillage estimates/thresholds)
- Waste processing
- Identity and location of end user

Proposals to overcome existing knowledge gaps in assessing pathways

It should be noted that nearly all options to overcome the difficulties with assessing pathways would require additional resources to those already deployed by countries to undertake inspections. The suggestions outlined would require industry and governmental buy-in as some sources of data would need to come from the industry collecting and releasing data, while others would require NPPOs in the importing and exporting countries to commit additional resources to gather the data (see Annex III for more details).

Point of Origin

- Improve/harmonise the nomenclature of commodity codes (more details, Latin name…)
- Send a questionnaire to the exporting NPPOs
- Literature and database search

Production Practices

- Search information about pest management

- Inspection or survey at the site of production (seeds)

Post-harvest Treatment

- Draw up commodity preparation guidelines for industry
- Review of quality assurance scheme guidance and customer supply chain standards
- Farm Surveys of post-harvest practices

Transport and Storage

- Commodity log book
- Inspection records
- Survey of logistics companies – biosecurity practices and industry standards for losses
- Review of country plant biosecurity legislation and guidance
- Review of transport times for commodities

Border Process

- Short term, targeted high-intensity inspection to gather information
- Review of work recording systems to identify inspection effort
- List of commodities/pathways agreed for reduced inspection effort
- Data from external agencies dealing with fraud, smuggling, etc.

End Use at Destination

- Guidelines on waste processing
- Find end user by supply chain survey
- Identification of proxies for end use
- Technologies to record links in supply chain

A short review of the options available to undertake systematic evaluation and prioritisation of the pathways is available in Annex IV.

2.5 Conclusions and recommendations to policy makers

The project shows that there is broad international support for pathways assessments. However, the discussions also showed that the way in which pathways assessments are being approached by different countries varies significantly. Under the current agreement on Sanitary and Phytosanitary Measures, quarantine or trade restrictions must be based on scientific principles and supported by scientific evidence. There is no current accepted best practice for using pathways assessments to justify restrictions on trade, and this would be a key requirement if a pathways approach were to replace the pest specific risk assessments currently used by most countries.

The key to robust pathway assessments is obtaining data about the pathways. It is technologically possible to collect the data required to monitor and assess the pathways of plant health risk. However, the systems used to record the data on trade and transport tend to maintain the compartmentalisation of this data. For example, different methods of transport require different sets of records, with goods travelling by air having a different information recorded compared to those travelling by ship, which is different again to recording systems for shipments made by road. Logistics companies maintain detailed records of shipments, but there is no central reference for these records. New technologies, such as blockchain, provide a solution for developing a system of centralised record keeping but the plant trade and horticultural industry may not welcome the additional burden or costs of introducing these systems.

A crucial part of operationalising pathway assessments is to ensure that all parties cooperate to complete the assessment. This means that it is important that there be benefits to both the importing and exporting countries of performing the pathways assessment. Having the exporter involved in the pathways assessment means that it reduces the number of risk assessments for non-active pathways, and assessing at the pathway level means that only one assessment is needed for that trade pathway, whereas multiple pest risk assessments may be required to cover the same trade. Finally, by using a standardised pathway assessment method all exporting countries will be assessed in the same way, demonstrating that there is no discriminatory practices against specific nations.

There are disadvantages as well to the application of pathways assessments. For simple cases where a specific pest risk assessment is relatively straightforward, the corresponding pathways assessment may be more complex and require the collation of redundant information. Therefore, pathway and species specific risk assessments both a have a role to play in managing plant biosecurity and can be used in combination to effectively manage risk from plant pests and diseases.

2.6 Benefits from trans-national cooperation

Pathways assessment is an inherently international process as pathway components cover both the exporting and importing countries. The information required for pathways assessment can only be obtained if there is international cooperation. The collaboration between the exporting and importing country is key to being able to properly assess the pathway. A pathways assessment clarifies the distribution of risk between components that originate within the exporting country, those originating within the importing country and those that are shared between the two. By cooperating on pathways assessment, the exporting and importing countries can support each other to minimise the risk on the pathway, benefitting both partners.

There are currently many approaches being taken to pathways assessment. Cooperation between countries can start to identify best practice, drawing on the expertise and experience of each nation’s plant protection organisations. This should help improve uptake and acceptance of pathways assessments, particularly with reference to fulfilling the requirement that SPS measures be based on objective scientific data and international standards, guidelines and recommendations

The development of a set of coherent methods for pathways assessment is vital to minimise the burden to countries in obtaining or supplying data for the assessment. If the assessment methods are standardised then the exporting country can prepare the required information in advance of a request from the importing country, shortening the time and resources required to undertake the assessment on both sides and improving both the biosecurity and ease of trade.

3. Publications

3.1. Article(s) for publication in the EPPO Bulletin

None

3.2. Article for publication in the EPPO Reporting Service

None

3.3. Article(s) for publication in other journals

None

4. Open Euphresco data

None

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Annex I Systems and methodologies to assess new and emerging pathways

The IPPC defines a pathway as ‘any means that allows entry and spread of a pest.’ (IPPC 2010). This covers a number of different forms of pathway, including different dispersal mechanisms (natural, human driven), intents (accidental and deliberate introductions), activities (e.g. traded commodities, tourism, scientific research) and modes of transport (air, ship, road and rail). This project is focussing on trade pathways, where a pathway can be defined by the commodity, country of origin and mode of transport.

World trade is continually evolving, with new trade links between countries for commodities being created on a regular basis. A new pathway would be defined as a pathway which has not existed before and would involve a new combination of commodity, country of origin and mode of transport. An emerging pathway is a pathway that already exists but that is experiencing a large increase in the quantity of trade moving through the pathway.

Review of methods and systems from partners

Fera

Following a review of methods for pathways assessment for Defra in 2016, Fera started work focussed on two systems that may be developed to help with the assessment of pathway risks. The first of these is a system to identify trade anomalies in plant trade data. In order to do this, a statistical model is fit that breaks the trade data, combining both quantities and prices for commodities, into three components; multi-annual trend, seasonal trend and residual trade. This data can then be used to detect anomalous periods where resources for inspections may need to be reallocated to deal with a risky new or emerging pathway. The development of this system is continuing, with the production of a prototype graphical user interface which allows interactive interrogation of the data and provides an automated warning system to flag anomalies for further investigation. The prototype has been presented to members of the UK Plant Health and Seeds Inspectorate, and to members of the Plant Health policy team in Defra.

The second approach builds a statistical model for the interception of pests based on the characteristics of the exporting country. These characteristics cover biological, economic and social metrics for the exporting countries and the relationship has been generated to predict annual interceptions in the EU from third countries using regularized and unregularized regression methods.

- The first regression method applies a Generalized Linear Modelling (GLM) approach to composite indicators derived by Principal Components Analysis (PCA) of the country’s characteristic data. The GLM can be fitted with a number of error and link functions which account for the type and shape of the data being fitted. A hurdle-negative binomial model was found to provide the best fit to the data, indicating there was overdispersion (higher level of variability), caused mainly by a larger than expected number of zero counts, compared to the idealised distribution of count data.
- The second regression method uses the Least Absolute Shrinkage and Selection Operator (LASSO) method. This is a regularization method, which means that it penalizes large coefficients and thus can be used to select the most important explanatory variables. This also means that whereas the GLM method is sensitive to

collinearity, leading to the use of PCA to make composite variables that are independent of each other, the LASSO method is capable of handling collinearity directly by choosing the most important of the colinear variables and shrinking the coefficients for the others to zero.

The results from the regression analyses appeared to perform well when considering the ranking of countries but were not reliable enough at predicting absolute numbers of interceptions to be used to assign inspection effort.

CFIA

The CFIA has conducted commodity risk assessments (CRAs) since the late 1980s, and follows the guidelines of the IPPC as described in ISPM No. 11 for pest risk analyses initiated by the identification of a pathway. CRAs are usually triggered by requests from the NPPO of an exporting country or from a Canadian importer to import products not previously imported or to import products from a new country of origin. The CRAs are qualitative and follow an established template. They evaluate a single commodity and list all the potentially associated pests, including insects, mites, and molluscs, fungi, bacteria, viruses and nematodes, weeds or invasive plants. Once the pest lists have been compiled, regulated and potential quarantine pests associated with the commodity from the country of origin are identified, as well as potential risk mitigation practices and/or recommendations for the organisms of concern. Examples of recent CRAs conducted by the CFIA include wheat from Kazakhstan, baby and sweet corn for consumption from India, *Prunus* fruit from Spain, apples from Japan and plums from Moldova.

Several common challenges have been noted by CFIA plant health risk assessors when conducting CRAs. Information on the commodity, including production and shipping practices as well as potential associated pests, may be lacking and/or difficult to obtain from the exporting NPPO. For information that is received, there may be inconsistencies in pest lists supplied by NPPOs and those obtained from other pest databases (e.g., CABI). Some pest lists can be lengthy and time-consuming to compile. Language of the relevant literature may be a confounding factor. As importers pay a fee to initiate risk assessments and expect standard completion times to be met, time constraints can also be a significant challenge.

Requests for CRAs are reviewed and prioritized by the CFIA. To help evaluate the priority of a request, the proponent who requests the CRA may be asked to complete a questionnaire. The priority level of a request may be raised if: 1) the PRA is identified as a priority by a Canadian industry association, 2) the product fills an identified need in the Canadian market and is expected to be imported in significant volumes, and 3) the exporting country's NPPO supports the request and is prepared to provide timely and thorough responses to the CFIA's requests for technical information (CFIA 2017).

Some measures have been put in place to expedite the pest risk analysis process for some commodities. For example, the CFIA's Horticulture Plant List (http://www.inspection.gc.ca/plants/horticulture/imports/horticulture-plant-list/eng/1419017863407/1419017907742) facilitates importation of 100s of pre-screened, low risk genera of plants for planting that are permitted entry into Canada from all countries other than the continental US with standard, basic phytosanitary import requirements. These plants do not require a risk assessment. Other measures may increase the emphasis on prevention of pest entry rather than mandatory phytosanitary treatment. This is the case with systems approaches for high risk commodities for Canada, such as temperate fruit. Systems approaches provide a means to produce and export horticultural products free of pests regulated by the importing country, and do so by employing multiple mitigation measures along the supply chain that together have a cumulative effect. To employ a systems approach, the NPPO of an exporting country must be able to demonstrate the efficacy of proposed integrated measures and should approve and oversee the places of production that use those measures. A systems approach may include a trial importation period in which consignments are tracked and subject to 100% inspection.

In addition to typical CRAs, the CFIA has conducted a number of risk assessments in keeping with the broader concepts of pathway risk analysis described in the North American Plant Protection Organization (NAPPO)'s Regional Standard for Phytosanitary Measures (RSPM) No. 31, *General Guidelines for Pathway Risk Analysis*. In RSPM No. 31, a commodity pest risk analysis is described as a special type of pathway risk analysis in which the pathway is clearly defined and which represents a collection of individual pest risk analyses grouped together based on a single commodity. However, pathway risk analyses can be highly diverse depending on the specific objectives of the analysis. Pathway analyses may evaluate pathways other than commodities or host plants, and may place the emphasis on how pathways affect the likelihood of introduction and/or spread of pests rather than on the consequences of the pests. They may evaluate some or all of the conditions or events on the continuum from origin to entry, establishment and spread in a new region and identify control points along the pathway that may provide opportunities for risk management. Examples of these types of analyses conducted by the CFIA include a risk analysis of grains as a pathway for weed seeds (Wilson et al. 2016) and a risk analysis of birdseed as a pathway for the introduction of invasive plants to Canada (in progress).

USDA APHIS PPQ

Like CFIA, PPQ produces CRAs to identify quarantine plant pests that could be introduced into the United States if an agricultural commodity is imported from a requesting country. Also like CFIA, PPQ's CRA methodology conforms with the guidelines set forth in ISPM 11 (PERAL, 2012). The current PPQ CRA guidelines characterize the likelihood of introduction and the consequences of introduction for quarantine pests that could move with a commodity (PERAL, 2012). The likelihood of introduction component evaluates the pathway and is qualitative and multiplicative. Consequently, if any step in pathway is found to be negligible for pest movement then the likelihood of introduction becomes negligible since the pest cannot complete the pathway.

PPQ uses variations of these guidelines to produce other types of assessments that have pathway components. These include export analyses that identify quarantine pests that could move on U.S. agricultural shipments to other countries and risk assessments for pests on plants for propagation coming into the United States from other countries.

In addition, PPQ also conducts pathway analyses to address specific phytosanitary issues. These pathway analyses can be qualitative, semi-quantitative, or quantitative and may use other methods e.g. GIS and predictive mapping, to help inform them (Fowler and Takeuchi, 2014). Examples include pathway analyses on the movement of thousand cankers disease into the eastern United States (Newton et al., 2009), pine shoot beetle movement into the southern United States on at-risk forest products (Fowler et al., 2006), and Asian gypsy moth movement on maritime ships from Japan to the United States (Fowler et al., 2008).

ANSES

Question: Transfers of fresh fruits and vegetables between countries via passengers or commercial trade enables insects such as Tephritidae (Diptera commonly named 'fruit flies') to colonize new areas, causing crop losses as well as displacement of indigenous species. Islands are very sensitive areas to alien species introductions, making application of import regulations important to protect local agriculture. In Réunion Island (Indian Ocean), 309 import pathways of fruits and vegetables have been identified using data registered between 2007 and 2012. The question, raised by the French Ministry of Agriculture to ANSES (French Agency for Food, Environmental and Occupational Health & Safety), was to rank the pathways representing a potential infestation risk by some of the 224 fruit flies species considered as the most threatening.

Methods: Two methods were developed: an information system, gathering information collected in databases, websites and publications, helped to identify the potentially infested pathways. A decision support system enabled pathways ranking according to the fruit flies hierarchy established using PROMETHEE multi-criteria method (Martin & Silvie, 2014).

Results: 55 risky import pathways were ranked, linked with potential infestation by 16 fruit fly species belonging to the genera *Anastrepha*, *Bactrocera*, *Ceratitis*, *Dacus* and *Rhagoletis.* Because of their high probability of entry and establishment, the threatening species would be, in order of importance, *B. invadens*, *C. rosa* (the African strain), *B. dorsalis* (separated from *B. invadens*), *B. tryoni* and *D. vertebratus*. The most risky pathways would be, in order of importance, fresh fruits from the genus *Citrus*, *Prunus*, as well as *Cucumis melo* and *Cucumis sativus*, all coming from South Africa, then Citrus imported from Madagascar and peaches from Zambia (ANSES, 2014a).

Conclusion: The ranking of pathways allowed by our method enables the customs risk manager to better define border management measures and to adapt the control of each pathway according to the threat linked to the fruit flies potentially conveyed.

This work was presented by Martin et al. (2015) and was also done for the remaining French Overseas Departments (ANSES, 2014b).

ILVO

'HarmVect', a tool generating pathway-risk maps for arthropods threatening the food safety in Belgium was developed in 2016. This tool, based on a generic model, is one of the many means for assessing and prioritising pathway risks with the aim of limiting the introduction of plant pests.

An essential approach is the tool's design in guiding the user to divide the complex arrival of the arthropod into all its potential pathways, which in their turn are further subdivided into individual pathway-segments. The manageable and singular pathway-segments are then used to specify which detailed data the user has to gather and feed to the tool. This information is used to simulate the magnitude of the arthropod population during the successive pathway-segments throughout each potential introduction pathway. The tool simulates the fluctuating propagule pressure throughout the successive segments of each pathway to calculate risk indices, which are then used to generate pathway risk maps of the arthropod for Belgium. The tool generates 2 types of pathway risk maps: (a) a Point-Of-Entry pathway risk map (POE) consisting of concentrated hotspots relating to the arthropod's entry at the national borders, and (b) a Point-Of-Appearance pathway risk map (POA), successive to the POE and visualizing the locations and level at which undetected propagules of the arthropod are exposed to the outside environment throughout Belgium. In conclusion, the tool produces an establishment risk map for the arthropods, which is generated by combining the POA with a climate-suitability and host-availability map.

The authors started off by describing all potential introduction pathways of an arthropod for Belgium and converting these descriptions into computer coded simulations. The tool has been constructed to run these simulations with the submitted data/information to estimate the various introduction risks of the assessed arthropod, which it then visualizes in risk maps. The tool is written in the R programming language (R Development Core Team, 2014). The tool is run in RStudio using the environment's app Shiny. Shiny is used to develop a user-friendly interface to guide the user through the tool and relieve him or her from having to work in the R-code itself. The interface is also used to obtain the detailed data/information necessary for the tool to run the simulations.

The tool was developed using the plant threatening arthropods *Tuta absoluta*, *Drosophila suzukii*, *Thrips palmi*, *Bemisia tabaci* and *Bactrocera invadens*, and the human and animal threatening arthropods *Aedes albopictus*, *Culicoides imicola*, *Anopheles gambiae*, *Rhipicephalus (Boophilus) microplus* and *Dermacentor reticulatus* as model organisms

As HarmVect is a generic model, the uncertainty/lack of detail related to the results of the analyses will be higher than in bespoke models for a specific arthropod. Consequently, the results of the tool should (currently) not be observed as accurate calculations of the risks, but more as a way of comparing the relative risks related to the different pathways, stages, times and places throughout the invasion of the arthropod. In addition, these relative risks can be used to evaluate different scenarios related to the invasion of the arthropod. As with most models, extra and more accurate data for Belgium (e.g. trade, host distribution, further distribution of commodities within Belgium, etc.) has to be made available to limit the uncertainty related to the current results generated by the tool.

Annex II Knowledge gaps regarding current industry practices in exporting countries

During the workshop held at ANSES in Angers, the project partners identified six pathway components , based on the conceptual diagram for the grain pathway described in Wilson et al (2016), for generic plant trade pathways, four of which exist in the pre-border space for the importing country or trading bloc, one involves the processes on the border at the point of entry into the importing country or trading bloc, and the final component represents the post-border processes within the importing country or trading bloc. The following knowledge gaps have been identified for each component of the pathway.

Point of Origin

Commodity composition

The commodity composition can be split into two parts, the commodity itself and the materials used to package and transport the commodity. The Harmonised System (HS) and Combined Nomenclature (CN) system for commodity codes are used for assigning customs tariffs and as such provides a universal set of agreed commodity codes for recording trade between countries. The HS and CN codes for plant products are highly variable in their specificity. For instance, many fruits and vegetables have been given an individual code while live plants for planting are split between seven HS codes, with most ornamental species likely to end up listed against the non-specific ‘Other’ code (HS Code 060299).

Many non-plant commodities are packaged and transported using wooden palettes or crates, and with plant based materials (i.e. straw, wood wool, etc) as packing. The origin and nature of these packing materials may mean that although the commodity itself is of low risk, the materials it is packed with may provide a pathway for the introduction of pests or diseases. Wood packaging material is believed to be the pathway for the 2012 outbreak of Asian Longhorn Beetle (*Anoplophora glabripennis*) in the UK (Straw et al. 2015) and for its introduction into the USA (Haack et al. 1997). ISPM 15 is designed to mitigate the risks from the wood packaging pathway, however it does not completely eliminate the pathway as the wood treatment may not be 100% effective at killing all pest organisms present or the wood packaging could be fraudulently marked as ISPM 15 compliant.

Country of origin

An individual consignment of a commodity may have a complex history of imports and exports. The country of origin may differ from the country of shipment, and there is also the ability to re-export which may obscure the true country of origin. This can lead to potentially misidentifying the level or risk associated with the commodity and the level of inspection required for the pathway. For instance, the EU has set minimum inspection requirements for a number of commodities, with a level of inspection which can vary depending on both the country of origin and the nature of the commodity. Also, for trading blocs like the EU there may be little information recorded with the commodity to identify the origin of the plants within the countries of that trading bloc.

Pest presence in the country of origin

There are two sources of uncertainty for the pest presence within the country of origin. The first is knowing whether an identified pest is established in the country. The second is whether there are species present which are not pests within their natural ranges but will become so when transported to a new country outside of their natural range.

The regional and national PPOs maintain quarantine lists which identify whether a known pest is regulated (quarantine or non-quarantine) and its status within the country. However, this only identifies pests that the country as an importer would be inspecting for. If a pest is not regulated within the importing country then this would not be listed in the NPPO pest list. So, while it is possible to identify if a pest is not present or is present but not widely distributed and under official control from the pest lists, it is not possible to say if a pest is present and widespread (and thus not requiring regulation) or absent and not considered as requiring regulation.

Identifying the risk from species which are not pests in their own natural ranges is a difficult task. For example the Emerald Ash Borer (*Agrilus planipennis*) was not considered as a pest until it established in the USA and Canada. It may however be possible to identify potential pests based on common traits for invasive species, such as species that demonstrate high reproductive rates, high dispersal capabilities and tolerance to a wide range of environmental conditions.

Socio-economic differences between exporting countries

It is unknown what effect the social and economic situation in the country of origin has on the uncertainty for many of the other pre-border components of the pathway. Least developed and low income countries may have little money to invest in systems to improve biosecurity and tackle fraudulent or illegal exports, and there is a key knowledge gap on whether socio-economic measures related to investment in infrastructure and regulation in the exporting country are correlated with the pathway risk for commodities between countries.

Production Practices

Pest risk management applied

Different levels of pest management can be applied to the production of a commodity. There can be differences in the availability of different pesticide products, both in terms of the compounds that are licenced for use against different pests and the way in which they are applied. Additionally there can be differences in the production practices themselves, such as the use of integrated pest management or whether production uses conventional or organic production practices. Soil associated with live plant commodities are a particular concern, and practices such as soil fumigation or heat treatment may be important in mitigating the soil pathway risks for those commodities where soil is transported along with the commodity.

Open field or greenhouse production

Different cultivation techniques produce different risks. There is less ability to control the conditions experienced by crops produced in an open field than under cover or in a glasshouse. Open field crops may be exposed to a larger number of pest or disease events than crops produced in more controlled conditions. However, glasshouse conditions can also benefit some plant pests and diseases, allowing exotic pests to survive in areas where the natural environmental conditions are not suitable or allowing high infestation or infection levels to build up during production leading to higher levels of infestation/infection in shipments than would be expected from open field crops.

Post-harvest Treatment

Standard for preparing commodities

At the point when crops are ready for harvesting there are a number of potential harvest and post-harvest treatments that may be applied. There is currently little understanding of what “best practice” means to each exporting country. Treatments that may be applied at the harvest or post-harvest stage include early harvest and controlled ripening, cleaning, application of coatings, fumigation and temperature control. Many of these options have two benefits, prolonging the life of fresh commodities and reducing the levels of pest and disease within the commodity. In addition, sorting the commodity during quality control (e.g. deformed or damaged fruit) may also reduce the level of pests and pathogens within the commodity.

Preparation of wood commodities is also an important post-harvest treatment process. Risks can be reduced significantly if the wood is debarked and treated in some way, such as heat treatment or fumigation. These are requirements under ISPM 15 if the wood is to be used as packaging but can also be applied to other wood commodities such as round wood, sawn wood, and wood chips. In the case of plants for planting or live cuttings, sprays or heat treatments can be applied to kill pests on the surface of live plants and cuttings.

Transport and Storage

Cross-contamination in storage and conveyances

While best practices would prevent cross-contamination, real world situations may provide opportunities for cross-contamination while commodities are being stored or transported. Consignments with different origins may be stored in close proximity, allowing transfer of pests or disease between consignments. Equipment and containers may be improperly cleaned between handling different commodities or consignments, again providing an opportunity for pests and disease to transfer from a contaminated load to an uncontaminated one.

Storage and transport conditions

Storage conditions can have a large effect on the risk associated with a pathway. If commodities are stored and transported in a controlled environment, with conditions set outside of the environmental tolerance of pests and diseases, then the pathway is likely to be less risky than if the commodity is transported and stored in an ambient environment.

Pest survival and multiplication in transport

Linked with storage conditions are the different sensitivities of pests to the characteristics of the transport. Pests and diseases may have different life stages which show different survivability within transport. Some life stages may be able to protect themselves better from the rigours of transport than others, for example being able to go into dormancy for extended periods of time. In some cases the transport conditions may not only be sufficient for pest survival, but may also be suitable to allow pests to multiply during transport. This is particularly important if part of the inspection process relies on pre-border checks at the point of export, or if there is significant post-border transport.

Border Process

Inspection priorities and sampling process

Inspection priorities can vary based on previous interceptions and the status of the pest within a country. Inspection priorities may vary across the year, taking account of seasonal variations in commodity volumes or expected pest pressure.

Logistically it is not possible to check every plant, fruit or vegetable that passes across the border between the exporting and importing country. In some cases only a proportion of the consignments for a commodity may be inspected, and even where 100% of consignments are inspected, often this involves detailed inspection of a proportion of the items in a consignment. Sources of uncertainty are the parameters that inspection agencies are using to perform the sampling of consignments, and the proportion of items within a consignment.

Ability to detect and detection methods

There are a number of tools available for inspectors to help detect and identify the presence of pest and disease within a commodity. However, in the main, it is a visual inspection looking for the pest or for characteristic symptoms that is employed. These visual assessments will not pick up where an infected/infested commodity is asymptomatic, or the symptoms are too general to diagnose a specific causal agent. New technologies are starting to make it possible to perform immunoassay and genetic testing at the border, but these tend to be applied as confirmation tests following a potential pest or disease being identified visually rather than as a screening process in their own right. Therefore, asymptomatic consignments, or commodities where pests and diseases may be difficult to see because of being located inside the commodity, in packing or in supporting media (such as soils), may not be identified as infested/infected without destructive sampling.

Illegal or accidental importation

This covers fraud and accidental misclassification of commodities. Fraudulent actions may include deliberate misclassification of a commodity to avoid inspection or tariffs, forgery of phytosanitary documents and marking up of untreated wood packing as being treated to ISPM 15 standards. The most likely reason for accidental importation is expected to be the misunderstanding of the use of commodity codes leading to misclassification of consignments. Other reasons could be errors in translation between common names used in the exporting and importing countries, and genuine errors in paperwork and record keeping. Where a prohibited plant or plant product is intercepted this may be identified and reported upon and the expectation is that incidents of accidental importation should be relatively low due to the multiple systems reliant on commodity information. However, the level of fraudulent activity may be difficult to quantify as fraudsters will be actively trying to avoid the measures which would detect an illegal commodity.

End Use at Destination

Risk of diversion of intended use

A number of commodities have multiple end uses. In particular commodities like cereals can be split into grains to be used for seed and grain destined for other uses. It may be that uncleaned grain that was destined for processing (where contaminants or infested grain would be removed and disposed of appropriately) instead gets used as seed. This may allow pests, diseases, or weed seeds to be released into the wider environment whereas certified seed grain would have been pre-screened to remove grain affected by pests, diseases, and weed seeds.

In-country storage and transport for importing country (spillage estimates/thresholds)

There will always be some losses in the process of storing and transporting of commodities due to accidents, human error or mechanical failures. Rates of loss claims are normally set by the buyer of the commodity, with loss claims made against the carrier rather than the seller. However, what is considered as an acceptable amount of loss before a claim would be filed is uncertain.

Waste processing

Many shipped commodities will produce waste when processed. This may include some of the more risky components of the commodity, such as damaged items, wood packing materials or soil associated with rooted plants. In some cases there may be processes in place to ensure that the risk from the waste is minimised, such as provision for heat or chemical treatment of waste, the processing of waste on site to minimise potential spread, and training of staff in biosecurity measures. The prevalence of use of these biosecurity measures may vary between commodities or within industries.

Identity and location of end user

There is little information on where commodities end up once they pass the border into the importing country. Not all end destinations will provide the same level of risk if a pest or disease were to be released into the wider environment. Likewise, if the majority of a commodity ends up in a particular location, then the risk that a pest could establish a viable population is much higher than if the commodity is spread out over many locations.

Annex III Proposals to overcome existing knowledge gaps in assessing pathways

It should be noted that nearly all options to overcome the difficulties with assessing pathways would require additional resources to those already deployed by countries to undertake inspections. The suggestions outlined would require industry and governmental buy-in as some sources of data would need to come from the industry collecting and releasing data, while others would require NPPOs in the importing and exporting countries to commit additional resources to gather the data.

Point of Origin

Improve/harmonise the nomenclature of commodity codes (more details, scientific name…)

There is currently a large amount of uncertainty about the species composition of commodities and the number of each species of plant that are being traded. In order to tackle this, better recording of the composition of consignments is needed. It is unlikely that this would be achieved through alteration of the HS code system as this is mainly to aid in the administration of tariffs. Instead an additional system that records species level information may be required, possibly achievable through a modification of the phytosanitary certification process. A key component for this would be the ensuring that the phytosanitary certificates are issued with a validated scientific name for the species.

Send a questionnaire to the exporting NPPO

One option for gaining more certainty about the pest pressure from different pathways would be to ask the NPPOs of exporting countries to provide information on the known established and native pests (potentially including emerging pests), levels and results of in-country inspection and industry uptake of biosecurity activities. A structured questionnaire with an agreed set of standard key questions may allow this information to be gather more easily, as the NPPOs will know what questions are being asked and be able to put processes in place to gather that information.

Literature and database search

Defining the pest list for a country could be aided by searches of published journal articles and searches of pest list databases such as the EPPO Global Database, CABI Crop Protection Compendium, CABI Distribution Maps of Plant Pests, Global Pest and Disease Database, Global Biodiversity Information Facility. These data sources would provide high quality, validated information on well-established pest presence but may miss the presence of emerging pests.

Production Practices

Search information about pest management

It may be possible to find information about best practice for pest management published by agricultural departments, agronomists and NGOs within each country.

Inspection or survey at the site of production (seeds)

For many companies there are internal processes which they use to ensure compliance with regulations and to ensure quality for their customers. Therefore it may be possible to request information from these companies on what standards they require their producers to meet and how they monitor compliance.

Post-harvest Treatment

Draw up commodity preparation instructions

One option would be to draw up a list of possible commodity preparation instructions. This would include all appropriate post-harvest treatments that could be applied to manage the pest and disease prevalence within the harvested commodity.

Review of quality assurance scheme guidance and customer supply chain standards

Many producers must adhere to quality assurance guidelines from certifying organisations or from the organisations they supply. A useful tool would be to identify what quality assurance products operate in each country and if they contain guidance on the types of post-harvest treatments that should or should not be applied.

Farm Surveys

It may also be possible to have a number of farm surveys undertaken to identify the prevalence of post-harvest treatment practices within the exporting country.

Transport and Storage

Commodity log book

A commodity log book would be a record of the history of the transport and storage of the commodity. In concept it would effectively be a blockchain record from the point of production to the point of use. This would mean that the journey of any consignment could be traced independently of the companies involved in the transport and storage and would also provide a way to identify the composition of mixed origin consignments. This could build upon existing systems, such as the CMR consignment notes which are required for international consignments carried by road.

Inspection records

For pest survival information, inspection records may provide information on the likelihood of live pests making it through transport.

Survey of logistics companies – biosecurity practices and industry standards for losses

One route for getting a better understanding of the management of biosecurity risk in the transportation and storage component of the pathway would be to undertake a survey of operating procedures employed by shipping companies for managing biosecurity. The shipping container industry has drawn up joint industry guidelines for best practice in inspection and cleaning of containers (COA et al, 2016). While the IMO and IPPC support the application of these guidelines, the actions in the guidelines are not mandatory, and it would be useful to survey across the container industry to identify the level of uptake of the guidelines.

Review of country plant biosecurity legislation and guidance

Individual countries may have legislation in place or provide guidance which impacts on the biosecurity of plants and plant products being moved within country. They may also have operating procedures for the holding of plants and plant commodities for export, such as maximum time that a consignment can be held in country before the phytosanitary certificate expires, or the requirement to seal goods after inspection.

Review of transport times for commodities

Many commodities arrive by a variety of transport methods, and the time in transport will vary considerably between these methods. Using shipping records would allow for a better understanding of how long consignments are in transit, particularly for multi-stage journeys where there may be periods during which containers sit in storage while they wait to be loaded onto the next ship, plane, truck or train.

Border Process

High-intensity inspection

Potentially one of the easiest ways to collect more data on the risk for particular pathways is to undertake short periods of high-intensity inspections at the border. This would entail increasing both the proportion of consignments and the proportion of items within the consignment inspected. This of course comes with increased resource requirements which mean that either existing resources would need to be diverted from other inspections or that additional resources would need to be brought in for the high-intensity inspections.

Review of work recording systems to identify inspection effort

Available statistics on interceptions tend to list the outcomes from only those inspections which result in a regulated pest being found. Recording inspection effort and negative finds would reduce the uncertainty in the pest risk associated with the pathway.

List of commodities/pathways agreed for reduced inspection effort

The list of commodities an inspection agency may target for reduced inspection effort will vary between countries and over time. For example, the criteria for commodities listed by the EU as available for reduced inspection is that less than 1% of inspected consignments of that commodity in each of the previous three years were found to harbour a harmful pest or disease, and that the commodity is not subject to temporary controls which would require full inspection.

Data from external agencies dealing with fraud, smuggling, etc.

Plant health inspectors can only properly inspect those consignments they are aware of. If commodities are entering the country associated with criminal activities then these are likely uninspected and could be of higher risk due to the origin, quality or conditions of transport. Linking up to information from organisations which monitor illicit trade may provide information of the volumes of commodities that bypass inspections by coming in through these pathways.

End Use at Destination

Guidelines on waste processing

Collating industry standard operating procedures or guidelines would provide information on the risk of release of a pest or disease into the local environment. Combining this with the volumes or proportions of commodities entering into the supply chains for these industries would provide finer granularity on which to make the pathways assessment.

Find end user by supply chain survey

Surveying the supply chain to identify the origin and trade within the supply chain for different commodities would provide information about the volumes and velocity of commodities being moved through the supply chain, the amount of internal trade within the supply chain and the volumes of commodities that get re-exported. All of these can be used to adjust the pathway assessment.

Identification of proxies for end use

There may be some recording of proxies for end use in existing trade or industry statistics. For instance, the ratio of novel seed corn sources in amount of corn sown from agricultural statistics could be used as an indicator of corn being diverted from processing to be used as seed (Fowler et al., 2014).

Technologies to record links in supply chain

There is increased awareness of sustainable sourcing in consumers. Being able to identify the providence of products is becoming more important to retailers. This brings pressure on industries to bring in systems which allow commodities to be tracked from their point of origin to end use. If technologies such as blockchain are widely employed within an industry then this may offer insight into the end use of inspected consignments once they are released at the border.

Annex IV Options for the systematic evaluation and prioritisation of pathways

Qualitative analyses use descriptive statements rather than numerical representations of risk. One justification often used for taking a purely qualitative approach is flexibility around hard data requirements. This makes them useful for screening purposes or emerging risks, where either the resource to collate data is limited or there has not been sufficient time to collect data before the assessment needs to be made. Despite being able to relax the data requirements for risk assessment by using a qualitative approach, it is important that the risk assessment is evidence-based and that the evidence is evaluated consistently (WHO 2009). There are a number of methods, such as the Delphi method, for eliciting robust qualitative information. One of the key actions when undertaking a qualitative assessment is to define the meaning of the descriptive terms used in order to remove some of the subjectivity associated with the use of natural language.

Semi-Quantitative

Semi-quantitative assessments occur when numerical values are used to represent descriptive terms. These systems are popular as they have similar data requirements to qualitative analyses but operate through the application of simple mathematical operations (e.g. minimum, maximum, addition and multiplication). However, it is with the assumption of objective representation that the greatest problems can arise and through which there is potential for the assessment to be manipulated. This is because it is possible to inadvertently or intentionally set the scores to up- or down-weight different aspects of the assessment. Thus it is important that the scoring system be independently peer-reviewed and presented along with the final scores.

The process by which a semi-quantitative system of assessment operates can either be additive or multiplicative. Additive scoring systems tend to contain a larger number of weighted scores than multiplicative systems that usually work on two (e.g. likelihood and impact) or three (e.g. threat, vulnerability, impact) weighted components (Hubbard & Evans 2010). Also, additive scoring systems can still produce a high-risk score even if some of the components of the risk are scored at zero, while a multiplicative system would always produce a zero risk if one of the components is zero. The two key complications with applying scoring systems are false beliefs about the meaning of the relationship among numerical values of scores, and the potential underlying subjectivity of the scoring system. These can be ascribed to four underlying problems:

- Cognitive biases: scores are attributed inconsistently, either by a single scorer or among different scorers, due to influence of external factors
- Variability in verbal labelling: different meanings are ascribed to the same label
- Invalid inference: the numerical meaning of the score is incorrectly interpreted. For example, assuming that scores follow a ratio scale and that doubling the score means doubling the risk
- Correlation of scores: one event occurring affects the probability or impact of a second event.

Some of these issues can be addressed by adding additional steps to the process through which the scoring system is applied, such as:

- Using quantified probabilities of occurrence and level of impact rather than descriptive terms
- Applying Monte Carlo simulations to identify correlations between risk scores
- Applying corrections for human bias in the assessment protocol such as calibration training of experts.

Quantitative

Quantitative pathway analysis is a data-heavy assessment framework in which the prevalence at the origin of the pathway, survival of pests within the pathway, and the opportunity for establishment is explicitly modelled. This is therefore a multi-disciplinary task that requires components of biological, social and economic modelling. Many of these model components are poorly understood including the modelling of survival during transport and the effect of a new environment on the spread and impact of a pest.

The quality of a quantitative risk assessment is dependent upon the accuracy, reliability, plausibility, scientific consistency and robustness of the data and models used (WHO/IPCS 2008). Hayes (2003) suggests modelling PRAs, which include a pathway analysis component, on the Quantitative Risk Assessment paradigm of:

- Hazard identification
- Frequency assessment
- Consequence assessment
- Risk calculation
- Uncertainty analysis

Hazard analysis tools, such as fault tree analysis and critical control points, can help explore the invasion mechanics of the pathway and identify weak links in the invasion chain (Hayes, 2003). Hayes (2003) also suggests calculating the total risk for a pathway using the following equation:

$$Risk_{Pathway} = 1 - \prod_{i=1}^{n}[1 - Risk_i]$$

Where there are *n* pest species (*i*) identified on the pathway and $Risk_i$ is the probability that species *i* will cause economic or ecological damage.

This equation effectively states that the risk for the pathway can be calculated by multiplying together all the protection scores (1-$Risk_i$) against each of the pests on the pathway and subtracting this from 1. The $Risk_i$ value can be modified to account for country, transport or commodity specific factors associated with the risk of introducing a pest.

Decision trees

Decision trees can be used to determine the appropriate type and detail of assessment to be undertaken. They represent a series of rules, which could for instance be informed by regulatory frameworks and agreements (Bremmer et al. 2012). The decision tree therefore represents a framework to define what to include in the risk assessment or pathway analysis, rather than being a method in itself to quantify risk. A decision tree can take account of an assessment of available data quality as well as the information in that data, and work particularly well where the risk assessment process involves tiers of assessments, where moving to the next stage of the assessment depends on the nature of the available data and the outcome of the assessment in the current tier.

Probabilistic Models

Probabilistic models can be used to conduct pathway analyses and provide quantitative estimates of plant pest introduction and spread. These models emulate the physical pathway and are composed the most critical components that determine plant pest movement and subsequent events, e.g. shipment volume, probability of pest establishment, etc. (Auclair et al., 2005).

Probabilistic models are often parameterized using distributions or point estimates which can be informed using a variety of sources including predictive mapping, expert opinion, and technical documents (Fowler and Takeuchi, 2012; Vose, 2000). Simulation modelling software is often used to run multiple iterations of the models in order to account for uncertainty.

Probabilistic models can be powerful tools for decision making because they provide quantitative estimates of an event's likelihood along with the associated uncertainty. A challenge with this approach can be acquiring the data to parameterize the model. When data for a given model component is lacking alternative sources like expert opinion or proxies can be used. Examples of probabilistic pathway analyses that were used for plant pest issues include Auclair et al., 2005; Caton et al., 2006; and Fowler et al., 2014.

MCDA

Multicriteria decision analysis (MCDA) tools are increasingly being used. Initially, MCDA was developed to help rank several alternatives from the best to the worst based on multiple criteria that could be in conflict (Behzadian et al., 2010). One of the main advantages of MCDA is that it allows consideration of a large number of criteria that may be measured in completely different scales, while it is not the case in classical risk analyses. Instead of trying to define what is good and what is bad, which can be difficult when facing new problems without reference, outranking methods are based on a more familiar way of thinking since it is much easier to compare one solution to another. Outranking methods model the way the decision-maker compares two alternatives (or actions) and use the results of pairwise comparison of the actions to build a relative ranking from the best to the worst. Outranking methods such as PROMETHEE are being extensively used in such exercises since it is considered to provide relevant and reliable results, and allows sensitivity analyses through the ability to change preference functions or criteria weights.

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