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ABSTRACT

There are considerable uncertainties associated with the radioecological simulation models used to predict the transfer of radionuclides along the food chain. Initially after an accidental release, the factors determining the contamination of foodstuffs will largely be defined by vegetation interception and the time of year. During the transition phase, factors controlling the uptake of radionuclides to vegetation from soil will become more important and these will dominate during the long-term rehabilitation phase. However, predictions made using radioecological models will be used in the early part of the transition phase to make longer-term decisions, e.g., with regard to remediation strategies. Therefore, models must be sufficiently robust and fit for purpose with uncertainties reduced where practicable.

The objective of the CONFIDENCE project's Work Package 3 is to improve the capabilities of radioecological models used to predict activity concentrations in foodstuffs and to better characterise, and where possible, reduce uncertainties. The focus of this deliverable is an evaluation of the FDMT (Food Chain and Dose Module for Terrestrial Pathways) as implemented in the JRodos and ARGOS decision support systems. We also present the results of a questionnaire survey sent to Japanese scientists to capture issues experienced in human food-chain transfer modelling in the first few months after the Fukushima accident.

The parameterisation of FDMT largely predates the latest international initiatives to collate radioecological transfer data; there has been some criticism that FDMT is not using state-of-the-art knowledge.

Although in many instances, the default transfer parameter values in FDMT are within an order of magnitude of those in the latest international compendium (I.e. IAEA, 2010), in a number of cases there is considerable disagreement between the FDMT and IAEA values. Therefore, it is recommended that FDMT be updated. Greater transparency is required on how default values in FDMT have been derived when data are lacking.

The ECOSYS-87/FDMT model has been successfully transferred to the ECOLEGO modelling platform. Data have been collated, primarily for element-dependent/radioecological parameters such as, soil to plant transfer factors and animal to feed transfer coefficients, to provide a 'current state-of the-art' update to the original ECOSYS-87/FDMT model. Unlike previous considerations of this model we have also collated underlying statistical information for parameters that enable uncertainty and sensitivity analysis. This new version of the ECOSYS-87/FDMT model has also been modified for regional conditions, examples specifically having been given for Norway and Spain.

A preliminary sensitivity analysis for selected cases (e.g. a given deposition of Cs-137 at a particular date) shows that the importance of different parameters changes with time for the selected endpoints (leafy vegetables and lamb meat) considered. Parameters such as retention coefficients and weathering rates being important in the initial phases following a deposition event and parameters dictating radionuclide soil processes becoming important at late stages – decades into the simulation. Soil to plant transfer for Cs-137 is an important parameter throughout most of the simulation period with the exception of recently after deposition (up to 2 months).

Implementation of FDMT within a modelling platform, such as the one described below, should allow components of the model to be modified and replaced, as required, and opens up the possibility of employing powerful numerical solvers to more challenging model configurations.

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1 Introduction

There are considerable uncertainties associated with the radioecological simulation models used to predict the transfer of radionuclides along the food chain. Initially after an accidental release, the factors determining the contamination of foodstuffs will largely be defined by vegetation interception and the time of year. During the transition phase, factors controlling the uptake of radionuclides to vegetation from soil will become more important and these will dominate during the long-term rehabilitation phase. However, predictions made using radioecological models will be used in the early part of the transition phase to make longer-term decisions, such as those associated with remediation strategies. Therefore, models must be sufficiently robust and fit for purpose with uncertainties reduced where practicable. A classic example of where predictions were made using models/information not fit for purpose is the post-Chernobyl case in upland United Kingdom when it was initialy stated that restrictions on sheep management as a consequence of high radiocaesium levels would last for a matter of weeks (Wynne 2016); the restrictions were in place until 2012.

The objective of the CONFIDENCE project's Work Package 3 is to improve the capabilities of radioecological models used to predict activity concentrations in foodstuffs and to better characterise, and where possible, reduce uncertainties. Our work programme addresses key challenges identified in the Radioecology ALLIANCE Strategic Research Agenda (Hinton et al. 2013) and specifically those of the Human Food chain roadmap (https://radioecology-exchange.org/sites/default/files/T1_WG_for%20Radioecology%20Roadmap_Human%20Food%20Chain_version02022015.pdf).

The focus of this deliverable is consideration of food chain transfer within the JRodos decision support system that is used in approximately twenty European countries as well as other countries worldwide (Raskob et al. 2018). The radionuclide food chain transfer module (FDMT) in JRodos pre-dates the latest compilations of parameter values (i.e. IAEA 1994, 2010) and does not take into account the large amount of data from studies conducted following the Chernobyl accident. Furthermore, radionuclide transfer parameters are often highly variable. We have therefore implemented the JRodos food chain model into a package that will allow uncertainty analyses to be conducted (including for different regional parameter data sets). One implementation of the model has been re-parameterised using the latest data compilations. The potential impact of regionalisation (e.g. as determined by climate type) is also considered.

Before considering the FDMT model however, we first present the results of a questionnaire survey sent to Japanese scientists on human food-chain transfer in the first few months after the Fukushima accident. This was conducted to determine if there were any lessons to be learnt from these relatively recent experiences.

Subsequent deliverables from CONFIDENCE Work Package 3 will consider the usefulness of process-based models in radiological assessment, application of extrapolation approaches when data are lacking, radionuclide biological half-life in farm animals, food chain transfer parameters for Mediterranean ecosystems, the inclusion of hot particles in radioecological models and the environmental behaviour of ^{131}I.

2 Survey of Japanese scientists on post-Fukushima issues and food chain modelling

From personal contacts following the 2011 Fukushima Daiichi accident, we became aware that a number of Japanese scientists involved in the response to the accident found that key radioecological material was lacking; including knowledge on some aspects of human food chain transfer. To try to gain more detailed information on what had been lacking we circulated a questionnaire (in Japanese and English; see Appendix 1) in summer 2017 to approximately one hundred Japanese scientists who were at that time involved in radioecology and radiation protection. The aim of the questionnaire was to identify elements of human food chain transfer for which knowledge was lacking, or where more information would have made assessments and predictions easier. We received twenty-three responses to the questionnaire (a rate typical for such a survey https://surveyanyplace.com/average-survey-response-rate/); responses are compiled in Appendix 1.

Sixty percent of responders stated that the information/data needed to understand radionuclide transfer to foodstuffs or make predictions was only 'sometimes' readily available. Issues raised with regard to radioecological knowledge of relevance to CONFIDENCE were:

- The need for transfer parameters appropriate to local conditions
- A need for an ability to predict changes in radionuclide activity concentrations in food products with time (including the need for biological half-life data)
- The lack of transfer parameters for specific foodstuffs (including the transfer of intercepted radiocaesium to fruit)
- Variability (uncertainty) in transfer parameters and problems in communicating this to non-specialists/the public
- Need for guidance on selecting suitable models (*circa*. 35% of respondents were not involved in radiation protection or radioecology prior to the Fukushima accident)
- Need for pre-accident training in responding to nuclear emergencies
- Need for reliable information sources
- How to deal with contamination of drinking water
- Food processing factors for radiocaesium

The work programme of CONFIDENCE WP3 (see Raskob et al. 2018) is addressing a number of the issues raised:

1. *The need for transfer parameters for specific food products that were also appropriate to local conditions* - the process-based modelling studies being conducted within CONFIDENCE aim to evaluate and develop models that will take into account important site characteristics (i.e. soil parameters). Of relevance to Europe, we are also collating/collecting radionuclide transfer parameters for Mediterranean production systems as these are currently lacking.
2. *Transfer parameters for some specific foodstuffs (e.g. bamboo shoots) were stated as lacking* - it is unlikely that data will ever be available for all of the foodstuff-radionuclide combinations needed. We therefore need reliable extrapolation approaches. Extrapolation approaches for wildlife assessment have been published (e.g. Beresford et al., 2016a; Brown et al. 2013) and a number of papers (e.g. Willey, 2010) have suggested that models based on phylogeny (evolutionary history) could be used to make predictions of soil-to-plant radionuclide concentration ratios. However, to our knowledge such an approach has not been validated for crop plants. We have conducted a greenhouse study using a number of different soils and crops to investigate the applicability of the approach as suggested by Willey (2010); the outputs of this work will be considered in our final deliverable.
3. *Variability in transfer parameters* – subsequent sections of this deliverable assesses the impact of variability in transfer parameters on end-point predictions (in this case activity concentrations in animal derived food products).

4. *A lack of biological half-life data for animal derived foodstuffs* - we have conducted a literature review; the resultant database is currently being prepared for publication.
5. *Predicting translocation of deposited radionuclides to fruits* – on-going field studies (see discussion in Section 6.1.1 of this deliverable) are investigating translocation of intercepted ^{131}I to fruit (strawberries).

The wider CONFIDENCE research programme is addressing some of the other issues raised such as communicating uncertainties and training (see Raskob et al. 2018).

3 FDMT

The FDMT (Food Chain and Dose Module for Terrestrial Pathways) software (Müller et al., 2004) has been implemented in both the "Real-time On-line Decision Support System" (RODOS, now referred to as JRodos) (Levdin et al. 2010) and the “Accident Reporting and Guiding Operational System” (ARGOS) (Hoe et al. 2008). The module allows for the prediction of radionuclide activity concentrations in various, mainly agricultural, food products for given inputs of radionuclides into geographically-specified terrestrial systems. The module, furthermore, allows the derivation of doses to members of the public via relevant pathways including internal exposure (from ingestion and inhalation) and external exposure (from plume passage and deposited radionuclides).

FDMT is largely based upon the earlier dynamic model ECOSYS-87 (Müller & Pröhl, 1993) that was originally implemented within Microsoft EXCEL™. Much of the developmental work including the numerical specification of many of the parameters used in ECOSYS-87 (and therefore FDMT) was completed in the 1980s and hence did not consider the large numbers of radioecology studies prompted by the 1986 Chernobyl accident. Furthermore, the original parameter collation was mainly specific to Southern German agricultural conditions although the model was designed to allow flexibility and adaptation to other conditions.

Subsequently, in this deliverable we compare radioecological parameter values in FDMT with the latest international recommendations (i.e. IAEA 2010). We also implement FDMT in a probabilistic-enabled modelling platform to explore (for selected key radionuclides - ^{131}I, ^{134,137}Cs and ^{90}Sr) the influence of regionalisation, perform probabilistic simulations and investigate sensitivity analyses.

3.1 Brief description of FDMT and how it is used in ARGOS/JRodos Decision Support System

The starting point for FDMT calculations are the outputs from atmospheric dispersion models (as also implemented within and connected to the ARGOS and JRodos systems). The main input quantities for subsequent calculations are:

- the date of the deposition (day, month)
- the time-integrated radionuclide activity concentration in near ground air
- the activity deposited by precipitation per unit ground area
- the amount of precipitation (for wet deposition)

Starting from these input data, the transfer of radionuclides through food chains is quantified by modelling various processes including the deposition and interception of radionuclides on vegetation/crop surfaces, the loss from vegetation/crops (via weathering), the change in radionuclide activity concentrations vegetation/crops via biomass dilution, and foliar and root uptake of radionuclides by vegetation/crops. A time dependency (i.e. deposition date) is included because both the canopy resistance for dry deposition and interception fraction for wet deposition are related to the leaf area index (LAI), which is in turn tabulated in terms of calendar date for different crop types. The foliar uptake is modelled differently depending on vegetation/crop type with application of translocation factors (describing the fraction of deposited activity transferred to the edible portions of the plant) defined for broad categories such as cereals and root vegetables. Root uptake is calculated via the use of soil-to-plant concentration ratio, F_v, (as defined in IAEA (2010)) but referred to as TF_i within FDMT (Bq/kg fresh mass (FM) plant to Bq/kg dry mass (DM) soil); note in IAEA (2010) F_v is defined on a dry mass plant basis). By definition, F_v, implies equilibrium or quasi equilibrium conditions in the soil-plant system many months post-accident (IAEA 2009). If deposition occurs during the growing season, a reduced root uptake is assumed via the application of a reduction factor (defined by the ratio of the time span from deposition to harvest the whole growing period, or 50 d if the growing period is longer than this).

The transfer of radionuclides from fodder into animal product is described by the feed transfer coefficient, F_m (for milk), F_f (for meat), referred to as TF_m in FDMT. The equations used to calculate radionuclide activity concentrations in the animal (or animal product) with time account for the dynamic nature of the system by considering the intake of activity from feedstuffs by animals over various time intervals and allowing for the loss/depuration of the radionuclide via biological excretion.

The radionuclide activity concentration available for root uptake is modelled by accounting for post-depositional processes occurring in soil, these being migration/leaching of the radionuclide out of the rooting zone and fixation in soil and subsequent desorption. The soil model is formalised as the analytical solution to a system comprising of two compartments, representing the activity available and not available (fixed) for plants, with transfers (as rate constants representing the three processes above) between and from the compartments (Fesenko et al., 1998). As default values, the desorption rate is set to zero in FDMT and fixation rates of 2.2×10^{-4} d^{-1} for Cs and 9×10^{-5} d^{-1} for Sr are assumed (the provenance of these values is unclear). For other elements, fixation is considered to be of minor importance and is set to zero.

3.2 A comparison of FDMT with the latest international data compilation

As noted above the radioecological parameters in FDMT originate from before the latest international initiatives to collate such data (i.e. IAEA (1994) which has subsequently superseded by IAEA (2010)); there has therefore been some criticism that FDMT is not using state-of-the-art knowledge (e.g. Neilsen & Andersson, 2008).

In this section we compare the default FDMT transfer parameter values for crops (F_v) and animal products (F_m, F_f) (taken from Müller et al. (2004)) to data presented in the latest International Atomic Energy Agency (IAEA) handbook (IAEA, 2010). The full comparison is presented in Appendix 2; arithmetic mean values were not presented in the IAEA handbook so these were obtained from the supporting information (IAEA, 2009). FDMT presents crop transfer parameters on a fresh mass basis whereas for all crops except fruit IAEA presents them on a dry mass basis. To enable comparison we have converted the IAEA dry mass values to fresh mass by applying dry matter content percentages as given in IAEA (2010); more information is given in Appendix 2. The IAEA compilations and FDMT do not use the same categories of crops, Appendix 2 provides information on what crop groupings from IAEA (2010) we have assumed map onto the groupings in FDMT. IAEA (2010), in theory, presents data for adult sheep meat (or mutton) and not lamb as given in FDMT. Consequently, we have calculated values for this parameter directly from the updated version of the database underlying IAEA (2010) (this database is held by the Centre for Ecology & Hydrology). However, we are aware that for lamb the database does not constitute a complete review as data sources known to the authors are missing. Appendix 2 gives a comparison of the FDMT lamb values with both the IAEA adult sheep milk value and our derived lamb values. We note that in some instances the IAEA (2010) values actually appear to be based on data for lamb.

Where comparison is possible 90% of the default FDMT F_m, F_f values are within an order of magnitude of the latest recommended IAEA value. Only the F_f for iodine and pork is more than an order of magnitude lower in FDMT than that quoted in IAEA (2009, 2010). However, for crops less than 70% of the default FDMT F_v values were within an order of magnitude of the value in IAEA (2010). Of the 10 values where the FDMT value was more than an order of magnitude lower than the IAEA value, seven of the comparisons were for Te. All of the Te values presented in IAEA (2010) are based on single values and hence confidence in them is low. The other values in FDMT which were more than an order of magnitude lower than the IAEA value were single values for Ce (grass), Mo (cereals) and Zr (root vegetables). Most of the 49 FDMT values which were more than an order of magnitude higher than in IAEA (2010) (some values were three to four-orders of magnitude higher) were for Ag, I, La, Na, Pu, Sb and Y. Figures 1 and 2 summarise the comparisons for animal product and crop transfer parameters respectively; see Appendix 2 for individual comparisons.

For 50% of the animal transfer coefficients included in FDMT and approximately 40% of the crop concentration ratios, there were no comparable data presented in IAEA (2010). In some case this maybe because the IAEA reviews have not captured all of the available data; for Tc transfer to animals products uncertainty in the available data meant that the IAEA handbook did not include any recommended values. However, in many cases FDMT has default transfer parameter values when we suspect that no data exist. For some animal products Müller & Pröhl (1993) describe how such data were derived: if data were not available for sheep and goat milk a value 10-times higher than that for cow milk was assumed. However, in many cases it is not always clear how the default parameter values have been derived when data were not available. From inspecting the default parameter values it can be surmised that assumption of similar element behaviour was assumed in some instances (e.g. the default parameter values for Rb and animal products are identical to those for Cs). In the case of crops it maybe that a value of 0.1 is assumed if data are lacking (e.g. all FDMT default F_v values for I, La, Nd, Pr, Rb and Rh are set at 0.1), however, this is only our speculation and it may not be correct.

We have used IAEA (2010) here for comparison with FDMT, in the case of goat and cow milk the database underlying the IAEA compilation has been reviewed/amended (Howard et al. 2016, 2017). However, values reported by Howard et al. are little different than those in IAEA (2010) or in instances where they are then both the Howard et al. and IAEA values are based on few data and are easily skewed by the additional/exclusion of single data points (Am and cow milk is a good example of this). Howard et al. (2017) does present a single value for Rb and cow milk, no value was presented in IAEA (2010), this is 6.5×10^{-3} so in agreement with the FDMT default of 1×10^{-2}.

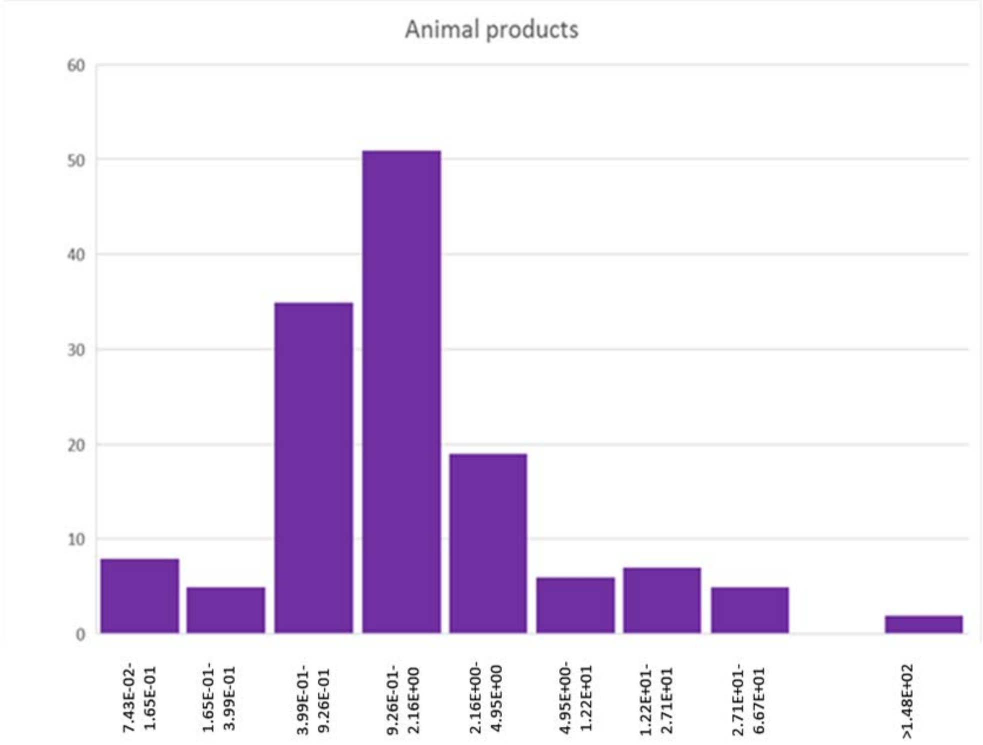

Figure 1. Distribution of the ratio between the default FDMT transfer coefficient values for farm animal products and the recommended value in IAEA (2010). A value of one would mean both data sources have the same value.

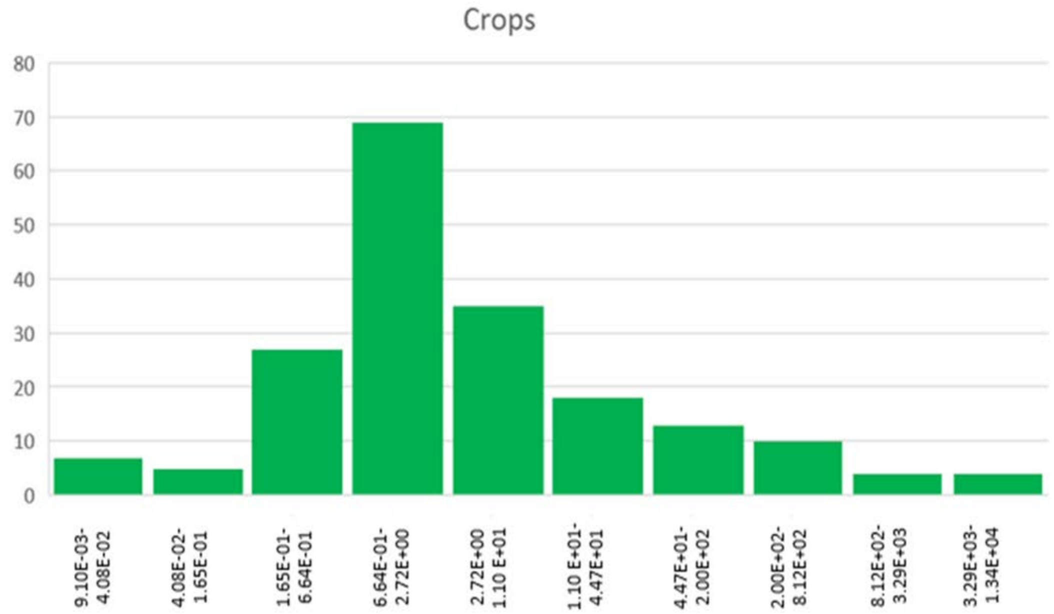

Figure 2. Distribution of the ratio between the default FDMT crop-soil concentration ratios and the recommended value in IAEA (2010). A value of one would mean both data sources have the same value.

Recommendations

Although in many instances, the default transfer parameter values in FDMT are within an order of magnitude of those in the latest international compendium (I.e. IAEA, 2010), in a number of cases there is considerable disagreement between the FDMT and IAEA values; **it** is therefore, recommended that FDMT be updated. The IAEA compendium also provides data to undertake probabilistic analyses should that be a requirement in the future (see discussion below).

It is evident that FDMT has many default values which are not based upon data. Greater transparency is required on how these values have been derived and indeed they should ideally be revisited taking into account data within IAEA (2009, 2010) and also the recent consideration given to extrapolation approaches to derive missing radiological data (e.g. Brown et al. 2013; Beresford et al. 2016a; Willey 2010). In the case of transfer to animals there is evidence that the tissue-diet concentration ratio maybe a more robust parameter than the transfer coefficient (Beresford et al., 2007, 2016a; Howard et al. 2009). The concentration ratio is not dependent upon the daily dry matter intake as the transfer coefficient is, and consequently, concentration ratios are relatively similar for a given element for different sizes and species of animals. Future studies in CONFIDENCE will consider the application of some of these extrapolation techniques to human food chain modelling.

The international data compilations have not considered radionuclide biological half-lives for farm animal products. Within CONFIDENCE we are currently finalising a review of biological half-life values which will be discussed, and compared to FDMT default values, in a subsequent deliverable (initial values extracted from this database for Cs, I and Sr are used in the analyses presented in Sections 4 and 5 below).

3.3 Limitations of FDMT

Apart from the lack of consideration of recent international recommendations/compilations of radiological parameters there are a number of limitations of FDMT. For instance, the current version of FDMT in the ARGOS and JRodos decision support systems utilises single parameter values and allows deterministic calculations. This is not, in principle, a highly problematic limitation and has the advantage of being straight-forward and easily implementable – if a specific value of deposition for a given radionuclide is provided as input, for example, the calculation returns single values for activity concentrations in a specified food-product at given times. However, the approach does not allow account to be taken of uncertainty in the simulation output despite the knowledge that large uncertainties exist in many of the parameter used in the calculation (e.g. see IAEA 2009). The importance of adequately characterising variability and uncertainty in exposure assessments for human health risk assessments has been asserted recently by Simon-Cornu et al. (2015) with reference to the emphasis already placed on this theme by several national and international organisations (e.g. EPA, 1997; FAO/WHO, 2006).

Another limitation lies in the fact that it is not practicable to undertake a robust, sensitivity analysis using the existing version of the model. Müller & Pröhl (1993) do present an initial consideration of uncertainty of the default ECOSYS-87 parameter values (some of which were relatively site specific) which identified the 21 most sensitive parameters from a total of more than 400 parameters. This work has limitations, mainly in relation to the specificity of the calculation (i.e. for a single case and endpoint) and some of the more simplistic assumptions regarding underlying statistical distributions that were made with triangular and uniform distributions commonly applied. In many cases more extensive underpinning datasets would have allow some refinement of distributions. Furthermore, it is evident that the greater number of data that are now available enable a more refined statistically-based model parameterisation; this will be discussed in more detail below.

Finally, there is an issue of flexibility. There are components of ECOSYS-87/FDMT where there are concerns over the robustness of the approach and where external (sub) models are available/published that may be considered as viable alternatives. An example can be given by the equations used to determine the concentration of plant available radionuclide activity in the root zone of soil. There are more sophisticated models available than the simplified approach described in FDMT where generic fixation and desorption rates are used across all soil types and migration/leaching rates vary between pasture and agricultural soils only because the depth of the rooting zone is assumed to be different. The 'Absalom model' (Absalom et al., 2001), for example, allows the radiocaesium bioavailability to be determined specifically as a function of soil clay content, exchangeable K^+ status, pH, NH_4^+ concentration and organic matter content. An evaluation of the Absalom model and other similar approaches will form the basis of one of our subsequent deliverables (see CONFIDENCE WP3 review paper initiating this work Almahayni et al. (submitted)). Furthermore, FDMT is not currently set up to allow the user to solve complex dynamic systems as essentially analytical solutions are provided for basic differential equations and simplifying assumptions are made with respect to, inputs to and losses from, various components of the modelled system. Implementation of FDMT within a modelling platform, such as the one described below, should allow components of the model to be modified and replaced, as required, and opens up the possibility of employing powerful numerical solvers to more challenging model configurations.

3.4 Recent work considering regionalisation of FDMT - COMET and HARMONE

As noted above, some preliminary efforts were made, starting with the work of Müller & Pröhl, (1993) to identify sensitive parameters within FDMT for a given specific case and thereby identify which parameters might best form the focus of further research effort. This has been superseded recently by the consideration (from a systematic and practical viewpoint) that data might be best organised on a geographical basis.

Preliminary regional adaptation of parameters was undertaken for several eastern European countries within RODOS (Raskob et al., 2000; Slavik et al., 2001; Fesenko et al., 1998), for Nordic countries (Hansen et al., 2010; Andersson et al., 2011) and for Ireland (RPII, 2007). Moreover, the COMET (Thørring et al., 2016a) and HARMONE (Staudt, 2016a; 2016b) projects have built upon earlier recommendations, from the JRodos and ARGOS communities, regarding adaptation of FDMT parameters for specific regions or sites (Pröhl & Müller, 2005; Raskob et al., 2000).

From the earlier discussions, it was evident that many of the factors that may influence transfer through agricultural food-chains, most notably the timing and length of the growing season and concomitant parameters such as LAI, feeding practices for animals and human diet will have a strong regional bias. Thørring et al. (2016a) specified important parameters in relation to regional adaptation (Table 1). Except for the category "Uptake from soil" (which is element-specific), all parameters belonged to an "element-independent" category and, as such, would have the same value for all radionuclides. Most radionuclide-specific parameters (e.g. physical half-lives, dose coefficients etc.) were considered, by Thørring et al. (2016a), to have generic geographical applicability and, therefore, were considered to have low/negligible priority in relation to regional updating. In contrast, element-dependent, or 'radioecological', parameters (e.g. soil-plant transfer, soil leaching/fixation) are known to vary with geographical location (as defined by soil type and climate etc.); these were defined as ???? priority

Within the COMET project, regional data for these element-independent categories were collated for Nordic (Norway and Finland) and Mediterranean (Spain) countries (Thørring et al., 2016a). Although there was originally a plan to collate information and parameterise FDMT with respect to radionuclide soil-plant transfer factors this was not done even though it was acknowledged that such parameters might be important in dictating long-term trends (Thørring et al., 2016a). Regional updates in soil-plant transfer parameter values were subsequently identified as a priority for future work (Søvik et al., 2017).

Table 1. Summary of important parameters in relation to regional adaptation (from Thørring et al. (2016a)).

Category	Parameter
Contamination of plants due to direct deposition	• Relevant growth periods • Leaf area indices (LAI) • Yields • Period of preparing winter feed
Animal parameters	• Animal specific feeding rations
Human habits	• Age-dependent consumption rates • Seasonality of consumption rates (if relevant)
Uptake from soil	• Transfer factors • Migration rates (if necessary)

Within the HARMONE project (Staudt, 2016a; 2016b) building on an approach developed within JRODOS, regionalisation was enacted by dividing Europe into five 'radioecological regions'. These radioecological regions were defined to match the biogeographical regions of the European Environment Agency namely: Alpine, Boreal, Continental, Atlantic and Mediterranean (https://www.eea.europa.eu/publications/report_2002_0524_154909/biogeographical-regions-in-europe). The approach is somewhat different to that of COMET which, for instance, specified three growing areas in Norway (for the collation of LAI, crop yield and harvest data) based upon the growing season start defined as the approximate date when the average temperature in a specified region exceeds 5°C. These zones are not correlated with the radioecological regions as defined by HARMONE for Norway.

The datasets collated within COMET for the parameters specified above (Table 1) were combined with data for other radioecological regions and expanded upon to cover a broader suite of parameters (and radionuclides) within the HARMONE project (Staudt, 2016a; 2016b). This study did attempt regionalisation of soil-plant radionuclide transfer parameters by assigning the values for sub-tropical environments from IAEA (2010) to the Mediterranean region and those from for temperate environments from IAEA to all other radioecological regions (with the exception that Sr and Cs values for Tundra climate were assumed to be applicable to the Alpine radioecological region) (Staudt, 2016b). The justification for having done this is however tenuous as the majority (*c.* 85%) of sub-tropical TF values in the IAEA compilations are for Bangladesh, Japan, Syria and Taiwan (IAEA, 2009). No data appear to be from Europe, unless any of that listed as coming from Turkey (*c.* 4% of the total sub-tropical TF values) was collected in Europe. The HARMONE data collation also covered some other parameter categories such as resuspension factors. However, other parameters, most notably data for radionuclide plant translocation factors and radionuclide migration/leaching rates in soils available in IAEA (2010) do not appear to have been updated in HARMONE.

Although there have been efforts to regionalise some of the parameters in FDMT there has been no attempt to consider the variability associated with the underlying datasets (which can generally be attributed distributions) and hence model outputs.

3.5 Objectives

By implementing FDMT in a probabilistic-enabled modelling platform, the possibility to be more flexible in terms of incorporating new components and sub-models is introduced and this further enables an exploration of the factors that introduce variability within model predictions (including model variants parameterised regionally). Such an implementation is described in the subsequent sections of this deliverable with the objectives to:

- Incorporate ECOSYS-87/FDMT within a modelling platform (ECOLEGO) that allows for modification of sub-models and probabilistic simulation
- Test and quality assure the ECOSYS-87/FDMT implementation on the ECOLEGO platform through comparison with the existing model configuration for given cases.
- Collate relevant and up-to-date statistical information for identified (primarily element-dependent/radioecological) parameters.
- Compare outputs (based on the statistical collations) from the new version of the model on the modelling platform with those from the old (default parameter) version of the model
- Explore the influence of regionalisation using recently published datasets
- Perform probabilistic simulations using updated statistical compilations
- Perform a proof of concept sensitivity analysis

4 Methodology - Description of implementation of ECOSYS-87/FDMT in ECOLEGO

4.1 What is ECOLEGO?

ECOLEGO (Version ECOLEGO 6.5.33) is a modelling platform for creating dynamic models and performing deterministic or probabilistic simulations (Avila et al., 2005; http://ecolego.facilia.se/ecolego/show/HomePage). The software incorporates powerful numerical solvers for complex and dynamic systems (i.e. solver for ordinary differential equations including 'stiff' problems) and provides support for probabilistic simulations using Monte Carlo or Latin Hypercube sampling.

4.2 How has ECOSYS-87/FDMT been implemented in ECOLEGO?

ECOSYS-87/FDMT has been incorporated within ECOLEGO by compartmentalising and structuring the system as per the original model set up (so that there are sub-models referring to units such as ‘grass extensive’, ‘maize’, ‘beet leaves’ and leafy vegetables’, ‘cow’ and ‘lamb’ etc.) and introducing the various links between compartments and equations governing each sub-system. The implementation has covered the entire suite of radionuclides and exposure pathways to humans that were included in the original ECOSYS-87 model although subsequent focus, in relation to collation of revised parameters, has been placed on the food-chain transfer components of the model. Default parameters are essentially those presented in the earlier version of the model (Müller & Pröhl, 1993; Müller et al., 2004). The ECOSYS-87/FDMT model within ECOLEGO can be viewed either as an interaction matrix or as a more traditional compartmental model set up (although strictly speaking the model is not a mass-balance type approach simulating flows between compartments) as shown in Figure 3.

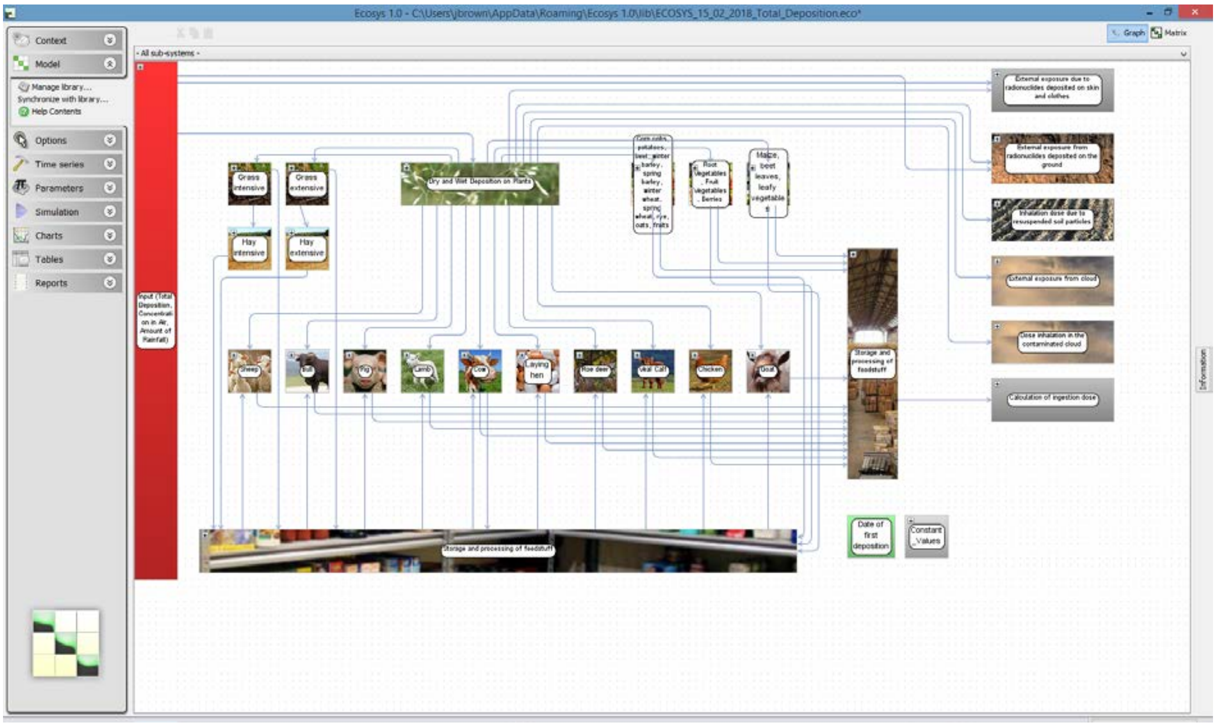

Figure 3. Model setup of ECOSYS-87/FDMT within the ECOLEGO platform.

4.3 Testing of the implementation using scenarios

Once ECOSYS-87/FDMT had been implemented into ECOLEGO we needed to test that the implementation was working correctly, i.e. to confirm that the results generated by ECOSYS-87/FDMT could be reproduced acceptably in the ECOLEGO implementation.

Within the COMET project (Søvik et al., 2017), two “simple” dry and wet deposition scenarios were specified “to study the effect of the parameter value updates on foodstuffs activity concentrations and intake doses for different age groups”. Within the scenarios, deposition date (1st August) and magnitude of deposition 1000 Bq m^{-2} for four radionuclides (Cs-134, Cs-137, Sr-90 and I-131) were defined. Using this scenario we have compared the ECOLEGO and EXCEL implementations of ECOSYS-87/FDMT for both wet (assuming 3mm of rainfall) and dry depositions. For both cases, the deposition date was assumed to be 1st of August with the assumed 1000 Bq m^{-2} depositions of each radionuclide (see Table 2 for other input parameters).

Table 2. Input parameters specified in the scenarios used to test the ECOLEGO implementation of ECOSYS-87/FDMT.

	Dry deposition Case	**Wet deposition case**
Simulated measurement (Bq/m^2)	1000	1000
Calculated activity concentration in air (Bq h/m^3)	140	0.55
Deposition on soil (Bq/m^2)	420	1000
Wet deposition (Bq/m^2)	0	1000
Total deposition to vegetated soil (Bq/m^2)	1000	1000

The input data for the dry deposition scenario required some additional pre-calculation (performed for this report using the ARGOS system) so that the integrated air concentration corresponded correctly to the defined dry deposition level. This reflects the methodology involving application of the so-called resistance approach in which individual surfaces/components of the ecosystem (i.e. atmosphere, plants surfaces, soil surfaces) can be modelled as a combination of resistances (using an electrical circuit analogy) in series and in parallel. The initial version of ECOSYS-87/FDMT in ECOLEGO did not include an accessible version of this dry deposition model and thus the option to modify parameters associated with deposition velocities was not available.

The original ECOSYS-87/FDMT in EXCEL and the new implementation in ECOLEGO were both run for a 5-year period, using default parameter values. The endpoints to be compared were radionuclide activity concentrations in winter wheat (whole grain), leafy vegetables, milk (cow), beef (cow) and lamb.

The results of the comparisons are discussed below and the detailed results are presented in Appendix 3.

4.4 Collation of underlying statistical datasets – default/generic data

EXCEL spreadsheets have been populated using data extracted from published reviews and elsewhere as described below. ECOSYS-87/FDMT in ECOLEGO has a function that allows a template listing all parameters of interest and required statistical information to be exported. This template can then be populated 'offline' with appropriate datasets before importing back into ECOSYS-87/FDMT in ECOLEGO for subsequent simulations.

The scenarios outlined above dictated the selection of parameters, for which to collate underlying statistical data. Thus, the collation was restricted to a suite of four radionuclides and designed to cover the list of foodstuffs mentioned above although the coverage was extended to all crop types because this involved limited additional effort. The goal was to cover as many parameters as practicable but certain constraints were introduced by the consideration that underpinning data were sometimes (expected to be) unavailable or the set-up of the model limited the statistical treatment of a given parameter. To explain this last point, it should be noted that some of the time-dependent parameters, such as LAI and translocation factors, in the ECOLEGO version of ECOSYS-87/FDMT are included as 'look-up' tables for which only single data values are allowed for each discrete time-point. It is therefore impracticable to assign distributions to these parameters. Nonetheless, the effect of changing these parameters is, in-part, assessed during our consideration of 'regionalisation' (see below).

As noted elsewhere (Sheppard, 2005; Simon-Cornu et al. 2015), it was considered that transfer factors (e.g. F_v, F_m, F_f) resulting from the multiplication of a large number of unknown positive parameters and their PDFs might be suitably characterised by lognormal distributions. It was hence considered appropriate to allocate lognormal distributions to the default transfer factors collated in the present analysis. In other cases, the coverage of the data was simply not comprehensive enough to allow a detailed PDF to be characterised. In such cases, uniform distributions were often employed allocating equal probability to the sampling of all quantities within the range defined by minimum and maximum values. In several cases triangular distributions were considered to be appropriate (see below).

The configuration of the default databases for the ECOLEGO implementation has drawn heavily on recent collations of radioecological parameter (most notably soil to plant transfer factor, and feed transfer coefficients for animal products) by the IAEA (IAEA, 2009, 2010). Detailed descriptions on data collation (giving information on their provenance and derivation) are provided below; the collated values and statistics for all parameters are presented in Appendix 4. Where possible below we make a comment on our view of data quality.

Retention coefficient (mm) of radionuclide i on plant type j – S_ij

In ECOSYS-87/FDMT, retention coefficients (S_i) are used together with leaf area indexes (LAI) and amount of rainfall (R) to calculate the interception of wet deposited radionuclides (Müller & Pröhl, 1993). Two plant groups are considered – group 1: grass, cereals, and maize; group 2: other plants. For group 1 plants, 0.1, 0.2, and 0.4 mm are used as defaults for I, Cs, and Sr, respectively; the corresponding values for group 2 are 1.5 times higher.

For the present work, the defaults from Müller & Pröhl (1993) are assumed to represent (arithmetic) mean values. The statistical data were derived from the Cs case study presented in Müller & Pröhl (Table 18), where it was assumed: that standard deviation (SD) was the same as the mean value; the minimum value was ¼ of the mean; the maximum was twice the mean; and that the data followed a normal distribution. We used the same assumptions to generate statistical data for I and Sr (see Appendix 4)

Note on data quality: The data used to derive retention coefficients in ECOSYS-87/FDMT are generally from reports that were unavailable to us and hence the quality cannot be evaluated. The statistical data are, as described above, based merely on assumptions (at least for Sr and I).

Vegetation weathering loss rates (d^{-1}), lambda_wi

Weathering half-life ($W_{t½}$) is a parameter describing the loss of contamination from plant surfaces from natural processes such as wind and rain. The default value used in ECOSYS-87/FDMT is 25 days for all radionuclides and crop types (Müller & Pröhl, 1993). Note that $W_{t½}$ (as defined in ECOSYS-87) does not include decrease from growth dilution of vegetation. The data used here were taken from the collation of Andersson et al. (2011) who note that, “it is not always clear whether the derived factors include growth dilution or not”. Consequently, the summary statistics used for the present study (Table 3) may be to some extent influenced by growth dilution. For more details, we refer readers to Andersson et al. (2011).

Table 3. Weathering half-life ($W_{t½}$, days) for different radioelement–plant combinations (where AM and AMSD are the arithmetic mean and arithmetic standard deviation respectively).

Plant group	Elements	AM	ASD	n	Min	Max	Notes
All	All	18.8	12.4	208	2.4	54	
All	All except iodine	23.2	12.3	138	3.1	54	(1)
All	Caesium	21.0	12.1	39	3.1	49	
All	Strontium	21.8	10.8	20	9.0	47	
All	Iodine	10.3	6.7	70	2.4	45	(2)
Grass	All	11.1	5.0	94	3.1	29	
Grass	All except iodine	13.9	5.4	37	3.1	29	(3)
Grass	Caesium	12.7	4.6	19	3.1	27	
Grass	Strontium	12.8	4.1	5	9.0	19	
Grass	Iodine	9.3	3.6	57	3.4	24	(4)

Note: values as used in the present study: (1) Cs and Sr leafy vegetables, maize and beet leaves; (2) I leafy vegetables, maize and beet leaves; (3) Cs and Sr grass; (4) I grass.

Weathering loss rates (lambda_wi) (days^{-1}), as shown in Appendix 4, were derived from Table 3 using the formula: $\lambda_{wi} = \ln(2)/W_{t½}$.

Note on data quality: Weathering half-lives and hence weathering loss rates (lambda_wi) are based on direct measurements from laboratory and field studies. The number of underpinning data are generally adequate for our purpose (i.e. provide us with enough information to say something sensible about the variance). As noted above the lack of clarity regarding the inclusion of growth dilution in many cases renders this dataset less robust.

Mass load of soil for plant j (g soil per g plant) R_j

There are a number of assumptions made concerning 'resuspension' in the ECOSYS-87/FDMT model (see p. 15 of Müller et al., 2004). The concept of the resuspension factor defined as '*the ratio of the volumetric activity density (in Bq m^{-3}) measured in air to the areal activity density (in Bq m^{-2}) measured on the soil surface'* is commonly used. This parameter depends on various factors including the material, the surface type and the time elapsed since deposition and the intensity of soil processing. A resuspension factor of 1x10^{-8} m^{-1} is equivalent (using various FDMT assumptions) to a soil-plant transfer factor of about 1x10^{-3} (the value actually used in the model) in terms of the activity contributed to vegetation from adherent soil. For Cs-137 at various sites and times the resuspension factor varies greatly from 1.6 x10^{-10} to 1 x10^{-5} (IAEA, 2009). For rural conditions, the model suggested in IAEA TRS-472 (IAEA, 2010) for use is that of Garland et al. (1992): the resuspension factor, $K_s(t) = 1.2\cdot10^{-6}\ t^{-1}$ (m^{-1}) where t is in days after deposition. This means that the range of Ks in the first year is from 1x10^{-6} to 3.3x10^{-9}. However, Garland et al. advised that this formula be applied to deposits older than 1 day and, after the Chernobyl accident, initial resuspension factors which were substantially lower (<5x10^{-8} m^{-1}) than would be predicted by the Garland et al. model were recorded. Therefore, values in the range 3.3x10^{-9} to 5 x10^{-8} m^{-1} have been used to define the range of 'equivalent transfer factors' using the FDMT relationship of resuspension factor to transfer factor. The mass load of soil on plant (R_j) has a range of 3.3x10^{-4} to 5x10^{-3} with a uniform distribution being assumed for crops (excluding grass) because the underpinning datasets are not comprehensive enough to allow the derivation of a more definitive PDF. Because of concerns relating to double accounting of soil intake by animals it was considered more transparent to account for soil intake by grazing animal directly (see below). Therefore, the parameter R_j was set to zero for Grass (intensive and extensive) model runs when deriving radionuclide activity concentrations in lamb and beef.

Note on data quality: The quality of the underpinning data for the parameter R_j is considered to be poor reflecting the lack of direct measurement, the reliance on a case specific empirical model and weakly supported assumptions characterising the relationship between an equivalent transfer factor and resuspension.

Enrichment factor for radionuclide I, (unitless) f_e_i

The ECOSYS-87/FDMT model employs an enrichment factor to account for the fact that resuspended soil fractions that end up as the mass load on vegetation surfaces are dominated by finer grained clay and silt fractions with concomitantly higher radionuclide activity concentrations than bulk soil. Due to a lack of underlying data, a single generic parameter value is used in FDMT for all soil types. Two classes of radionuclides are considered in the estimation of the enrichment factor based on whether they are predominately present in anion or cationic forms in soils. Whilst default enrichment factors of 1 are used in FDMT for I and 3 for Cs and Sr, the FDMT-ECOLEGO version had values for all three elements set to unity.

There appears to be no means, via the option to modify a bespoke parameter within the ECOSYS-87/FDMT, of accounting for the relative bioavailability of radionuclides to reflect whether they are associated with ingested plant material or with soil. For some radionuclides, the difference in bioavailability associated with different dietary sources of radionuclides can be relatively substantial

(Beresford et al., 2000). A simple means of accounting for this phenomenon and avoiding the introduction of additional parameters, is to modify the f_e_i parameter accordingly. In this way, the modified version of the parameter can be used to account for the combination of activity contamination enrichment in resuspended soil and the subsequent bioavailability of the radionuclide to the grazing animal. For radiocaesium, f_e_i has been modified to account for the bioavailability of ingested soil (Beresford et al, 2000) and an enrichment of 2 (average value) from Sheppard (1995); the value of f_e_i used taking account of potential differing bioavailabilities is 0.25. For radiostrontium, an enrichment of 1-3 (range) has been taken from Sheppard (1995). The bioavailability of Sr from soil is however the same as vegetation (Beresford et al., 2000). For radioiodine, no modifications have been made, the bioavailability is considered to be the same for all potential dietary sources (Beresford et al., 2000) and there is no evidence of enrichment. The short physical half-life of ^{131}I means that this parameter is unlikely to be important in any case.

The statistical coverage of these datasets was poor but owing to the availability of a range of values and best estimate value, the attribution of a triangular distribution was considered justifiable.

Note on data quality: Confidence in the parameter f_e_i is considered to be low, primarily because its derivation is based upon the multiplication of two somewhat uncertain components, namely the enrichment factor itself and the bioavailability of radionuclides in the soil adhered to vegetation.

Soil-plant transfer factor for radionuclide, (unitless) TF_ij (Fv – concentration ratio)

Soil to plant concentration ratios have been extracted from IAEA (2009, 2010). A conversion factor (from IAEA (2010)) needed to be applied because, as discussed above, values in IAEA (2010) are reported as DM vegetation to DM soil, whereas FDMT values are for FM vegetation. Soil to plant concentration ratios for different plant categories are further categorised in terms of soil type in IAEA documentation (refs). For all vegetation categories with the exception of grass-extensive, statistical information has been derived for summarised IAEA data for 'all soils'. For grass-extensive a value for organic soils has been used reflecting the usual soil type associated with rough pastures in Europe. A log-normal distribution has been assigned to each of the concentration ratio datasets based on the arguments given above (see Simon-Cornu et al., 2015; Sheppard, 2005). The geometric means from these data compilations are used as the new default parameter values for deterministic runs whilst the arithmetic mean and distribution data are used for probabilistic modelling. In some cases where direct empirical data were not available, information has been derived from a broader crop categorisation. For example, in the case of iodine and maize, the transfer factor for I to the broad group cereal (stems and shoots) has been used. This information is provided in the excel spreadsheets that underpin this analysis (Brown et al. 2018).

Note on data quality: The characterisation of parameter TF_ij may be generally be considered to be supported by relatively large datasets for Cs and Sr at least; data for I are not so numerous.

Soil intake by grazing animals, (g/g) S_j .

Soil ingestion by grazing animals is assumed in FDMT with a default mean annual soil intake of 2.5 % (*fsi* = 0.025) of the grass dry matter intake being assumed (see p. 19 of Müller et al. 2004). The default value of the parameter *S_j* used in the FDMT is 0.005 (g soil per g vegetation) derived by correcting the assumed *fsi* value to a fresh mass intake basis (i.e. assuming 20 % dry matter). This nuclide-independent value is in-effect, equivalent to a soil-plant transfer factor of 5×10^{-3}. Numerous factors affect this parameter (Beresford & Howard, 1991; Green et al., 1996), including land management and how different animal species graze. A number of models use values higher than in FDMT (e.g. see discussion in Beresford & Howard 1991). We have used ranges of soil contamination of vegetation taken from Sheppard (1995) for sheep and cattle to derive a best estimate value; the statistical coverage of these datasets was poor and a triangular distribution was assumed. Values from Sheppard were divided by five to convert them to a fresh mass basis (i.e. assuming 20% DM as used in FDMT).

Note on data quality: This could be considered a relatively poorly characterised dataset compared to e.g. that available for many F_v values.

Transfer coefficients – Lamb, cow meat (d/kg) and milk (d/L) – TF_ik_animal product

A log-normal distribution has been assigned to each of the transfer coefficient datasets. As for soil-plant concentration ratios the geometric means from these data compilations are used as the new default parameter values for deterministic runs whilst the arithmetic mean and distribution data are used for probabilistic modelling.

TF_ik_meat (F_f) cow meat (d/kg) and TF_ik_milk (F_f) milk (d/L)

Statistical information on transfer coefficients for cow meat and milk was extracted from IAEA (2009) and IAEA (2010) for Cs, I and Sr.

TF_ik_meat (F_f) for lamb (d/kg)

Values could not be extracted directly from IAEA (2010) because as discussed above the presented data were nominally for adult sheep meat (or mutton) only. Consequently, we have calculated values for this parameter directly from the updated version of the database underlying IAEA (2010). The values derived, as given in Table 4, are means of the individual data entered values in the database, which may be single values or means; whilst this may not be the ideal approach it is consistent with that used in IAEA (2010) (so 'n' in Table 4 is the number of entries not animals as it is in IAEA 2009, 2010). Furthermore, as noted above we are aware that for lamb the database does not constitute a complete review as data sources known to the authors are missing.

Table 4. Lamb F_f values for Cs and Sr estimated for this work from the updated database underlying IAEA (2009,2010).

Element	AM	ASD	GM	GSD	Max	Min	n
Cs	0.867	0.385	0.797	1.573	1.61	0.36	7
Sr	2.58E-3	1.08E-3	2.36E-3	1.693	3.70E-3	1.10E-3	4

GM and GSD are the geometric mean and standard deviation respectively.

Iodine – IAEA (2010) has only one value of iodine F_f for mutton, whilst the updated database has two relatively similar values for adult sheep (of 3E-2 and 2E-2). However, in total, there are seven dietary concentration ratio (CR_{diet}) values (i.e. the ratio of the fresh mass activity concentration in meat to the dry matter activity concentration in the diet) across sheep, beef, pork. The CR_{diet} has been proposed as a parameter, which should be relatively constant across species (Beresford et al. 2016a; Howard et al. 2009). An F_f value can be calculated by dividing CR_{diet} by the daily dry matter intake rate. The summarised iodine F_f values estimated for lamb presented in Table 5 were estimated from the CR_{diet} values (for all species) as presented in IAEA (2010) and an assumed dry matter intake rate of 1 kg d^{-1}.

Table 5. Lamb F_f for I derived from CR_{diet} values presented in IAEA (2010).

AM	ASD	GM	GMSD	Max	Min	n
7.78E-2	6.49E-2	5.82E-2	2.27	1.88E-1	2.03E-2	7

GM and GSD are the geometric mean and standard deviation respectively.

Note on data quality: The characterisation of parameter TF_ij_animal for the three radionuclides considered here for milk are supported by a relatively large datasets. The same is the case for Cs and Sr for beef, though data for I transfer to the meat of any animal type is poor. For lamb, relatively few data have been used to derive the values in Table 4 for Cs and Sr. However, the values 'look sensible' compared to the larger mutton datasets in IAEA (2010) (i.e. they are higher than the adult values as would be anticipated). However, in general, as noted above, the transfer coefficient is not an ideal parameter as its calculation is influenced by dry matter intake.

Biological half-life values, bio_half_life_animal (d) and a_ij_animal (fractional component)

Whilst many models use biological half-lives (or rate constants derived from them) to describe the rate of loss of radionuclides from animal tissues and products neither of the relevant IAEA reviews (IAEA 1994, 2010) have considered this parameter. Therefore, during CONFIDENCE we are establishing a biological half-life database for farm animal products, which will subsequently be published (as a database). At the time of writing the database, which is undergoing final quality control checks, contains over 600 entries. However, the biological half-life database is not as easy to summarise statistically as that for F_f values because, for a given animal product-radionuclide combination, different entries may record a different number of components of loss. Therefore, some degree of expert judgement was used in selecting the values presented below; only data from studies where radionuclide intake had been oral were used in the selection of parameter values. Similarly, pragmatism had to be used in deriving fractions attributable to each component of loss. Fractions attributable to the different components of loss (i.e. a_ij_animal) should always add up to unity and these parameters were expressed without a distribution to avoid any oddities when combining them. It was possible to assign minimum and maximum values to the biological half-life values and to derive best estimate values; triangular distributions were applied.

Cow Milk

Iodine – Some studies in the database have a second longer component of loss ranging from a few days to 20 d. However, generally there is no associated a_ij_animal value. Approaching half of the 30 studies report only a single loss component. The arithmetic mean of the single half-life or first component half-life over all 30 studies is 1.03 d (range 0.6 to 2.1 d). Based upon this, a single loss component of 1 d has been assumed.

Caesium – Nineteen database entries show two components of loss and can be summarised as:

$T_{1/2(1)}$ average of 1.4 d with an a_ij_animal value of 0.8

$T_{1/2(2)}$ average of 15 d with an a_ij_animal value of 0.2

Strontium – For Sr multiple components of loss may also been expected. However, only single components of loss are recorded in the database. From five entries an average value of 2.4 d can be estimated.

Beef

Iodine – There are two studies in the database, one with single loss component of 7d and the other with two components of loss, 1.7 d and 9 d (a_ij_animal = 0.47 and 0.53) respectively. In reality, these two studies show a similar rate of loss and a $T_{1/2}$ value of 7 d has been assumed.

Caesium – Eleven database entries show two components of loss and can be summarised as:

$T_{1/2(1)}$ average of 9.3 d with an a_ij_animal of 0.56

$T_{1/2(2)}$ average of 53 d with an a_ij_animal value of 0.44

Strontium – Four database entries show two components of loss and can be summarised as:

$T_{1/2(1)}$ average of 3.6 d with an a_ij_animal of 0.59

$T_{1/2(2)}$ average of 325 d with an a_ij_animal value of 0.41

We should acknowledge that there is considerable variation in the second component (ranging from 180 to 650 d)

Lamb

Iodine – There are no entries in the database and hence the same value (7 d) has been assumed as for cattle.

Caesium – The database has fifteen entries with single components of loss giving an average value of 16 d (range 12-24 d). Perhaps, intuitively, more than one loss component would have been anticipated. However, the database only has two studies showing two components of loss and these were not in agreement with each other. Therefore, we have assumed a single component of loss with a $T_{1/2}$ value of 16 d.

Strontium – Only two studies in the database both of which report two components of loss. Evaluating these studies we have assumed the following:

$T_{1/2(1)}$ of 3.5 d with an a_ij_animal of 0.9

$T_{1/2(2)}$ of 325 d with an a_ij_animal value of 0.1

Note on data quality: Often these values are based upon few data and, as discussed, summarising biological half-life expressions involves an element of expert judgement. As noted, some of the values selected are perhaps not what would be expected (e.g. single component of loss for Cs and lamb). We should also note that the database is provisional and undergoing a final quality control check and hence the values as used here should be considered provisional.

Soil density

The FDMT default soil bulk density (BD) is 1400 kg/m^3 (DM). Most mineral soils usually range between 1000–1600. Generally, soils with BDs above 1600 kg/m^3 will limit root growth, and such soils are therefore not practical for agricultural use. A strong relationship between BD and organic matter (OM) content has been reported by several authors. For instance, Harrison & Bocock (1981) provide the following relationship for all surface soils:

$BD = 1558\text{-}728 * LOG_{10}(OM)$

Organic soils (defined as having OM>20%) generally have a BD <600 kg/m^3. Highly organic soils with OM >95% may have BDs of 100 kg/m^3 (or even less). Two "types" of soil are considered in FDMT, agricultural soil (0-25 cm) and pasture soil (0-10 cm); pastures are divided into intensive (I) and extensive (E) groupings.

Agricultural soil (0–25 cm): The OM content in more than 500 000 soil samples (0-20 cm) from the whole of Norway was available through Grønlund (2009). The data, covering the period 1996–2007, are mainly for agricultural soils used for the production of cereals, potatoes, vegetables and grass. Note that only summary statistics (AM, ASD, N) from municipalities were available, not individual data; Norway is split into 422 municipalities and most of them were covered by these data. We generated a weighted mean and standard deviation for the whole of Norway using the method from Hosseini et al. (2008), resulting in a value of 7.4±9.0%. From these data, GM (4.7%) and GSD (2.6) were derived using equations from Thørring et al. (2016b). Based on the GM (=mode) and range[1] for OM, BD was estimated using the Harrison & Bocock equation, resulting in a value of 1100 (470–1700) kg/m^3 DM. A triangular distribution was assumed for simplicity.

Pasture soil (0-10 cm): BD data from various pastures in Norway were collated from unpublished and published sources (e.g. Thørring et al. 2012; Rosen et al. 2012). Since we did not have enough information to determine any "mode" BD for pasture, uniform distributions were specified – with ranges 200–1700 and 100–600 kg/m^3 for intensive and extensive pastures, respectively. Note here that the lower range for extensive pastures is in accordance with the definition above (i.e. organic soils have an OM>20%).

Note on data quality: The data used to characterise soil density are from Norway, and different ranges could be more suitable for other regions in Europe. Nonetheless, for the purposes of this deliverable the rather extensive datasets and large ranges specified can be considered to be indicative of the

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[1] Range was calculated assuming 2 GSD

statistics that might be expected for European soils. In support of this observation, the bulk density of 2570 soil samples (0-15 cm) collected from across Great Britain was 780±442 kg m^{-3} (mean±SD) ranging from 22 to 1950 kg m^{-3} (Emmett et al., 2016).

Radionuclides in soil: fixation/desorption rates

Default fixation rates in ECOSYS-87/FDMT are 2.2 x 10^{-4} d^{-1} for Cs and 9 x 10^{-5} d^{-1} for Sr. According to Müller & Pröhl (1993), these data were taken from Frissel & Koster (1987). For other elements fixation is regarded to be of minor importance – e.g. a fixation rate of 1.90 x 10^{-6} d^{-1} is used for I in FDMT. For the present study, only Cs fixation was considered, and the default desorption rates of zero were kept. For more about desorption rates in FDMT we refer to Nielsen et al. (2009). Regarding fixation of Cs, Tarsitano et al. (2011) used a time constant for slow soil fixation of 2.73 x 10^{-4} days^{-1} with a standard error of 8.50 x 10^{-5} days^{-1}. This corresponds to a $T_{1/2}$ from fixation of 7.0±2.2 years. More rapid fixation was reported by Nielsen et al. (2009), assuming exponential decrease, with $T_{1/2}$ between 1.3–2.7 years for most soils, and 4–5 years for sandy and organic soils. In Bergan et al. (2000), fixation rates of added Cs-134 tracer were reported to be within the range <1.0 x 10^{-4} – 5.9 x 10^{-4} d^{-1} for soils from various sites in the Nordic countries – corresponding to $T_{1/2}$ between 3.2 and >15 years. Since the latter data correspond well with Tarsitano (2011) and the FDMT default, we have simply used the range 1.0 x 10^{-4} – 5.9 x 10^{-4} d^{-1} for the present work, assuming a uniform distribution.

As evident from the above, available data to characterise fixation rate of Cs are rather scarce. It is difficult to evaluate the quality of the default values, since the work by Frissel & Koster (1987) (as cited by Müller & Pröhl (1993)) was not available to us.

Migration of radionuclides out of the root zone (λ_{ai})

Default values for migration rates as originally used in the model are given in Table 6.

	Cs	**Sr**
Arable	1.9E-5	3.8E-5
Pasture	4.7E-5	9.6E-5

Table 6. Default λ_{ai} (day^{-1}) for FDMT taken from Müller et al. (2004).

Note that a different approach to that used in FDMT was used in ECOSYS-87 (Müller & Prohl, 1993). The reasons for this change are discussed in Müller et al. (2004) (p 14-15). For our study, statistical information on λ_{ai} (day^{-1}) were derived using migration rate (MR) data (cm/a) compiled in IAEA (2009). Cs-137 MR data from undisturbed grassland (Table 2, p 108 of IAEA (2009)), based on all available values from the surface to 10 cm depth, were used directly for both arable and pasture soil. This was due to lack of necessary information for arable soils. MR data for Sr-90 data are more limited than those for Cs-137 and are divided in three groups (Table 4, p. 114 of IAEA (2009)): nuclear weapons fallout (NWF), Chernobyl deposition and artificial contamination. For our collation, data from NWF and Chernobyl fallout were merged and statistical parameters derived using the approach from Hosseini et al (2008); artificial contamination studies were not considered. MR data for iodine were so limited that no attempt was made to calculate λ_{ai}. However, I is likely to be mobile in soil (see e.g. Soderlund et al. 2011).

The following equation was used to convert the MR data to λ_{ai} (Table 7):

$$\lambda_{ai} = (\ln(2) \times MR)/(L \times 365.25)$$

where,

λ_{ai} = rate of activity decrease due to migration out of the root zone (day^{-1})

MR = migration rate (cm/a)

L = thickness of soil layer considered (cm). Note that L=10 cm was assumed for pasture and L=25 cm for arable soil

Table 7. Soil migration data for Cs-137 and Sr-90

Radionuclide	ID	AM	ASD	N	Min	Max	GM	GSD
Cs-137	MR	6.0E-1	1.2E+00	58	4.0E-2	1.0E+01	3.4E-1	2.6
Cs-137	λ_{ai} (10 cm)	1.1E-4	2.3E-4	58	7.6E-6	1.9E-3	6.5E-5	2.6
Cs-137	λ_{ai} (25 cm)	4.6E-5	9.1E-5	58	3.0E-6	7.6E-4	2.6E-5	2.6
Sr-90	MR	7.1E-1	4.2E-1	28	1.2E-1	1.5E+00	6.2E-1	1.7
Sr-90	λ_{ai} (10 cm)	1.4E-4	7.9E-5	28	2.3E-5	2.8E-4	1.2E-4	1.7
Sr-90	λ_{ai} (25 cm)	5.4E-5	3.2E-5	28	9.1E-6	1.1E-4	4.7E-5	1.7

Note on data quality: The nature of this dataset makes any comment on data quality challenging. The number of underpinning observations is substantial for radiocaesium and reasonable for Sr-90 but the assumptions that are introduced to derive the MR parameter render the evaluation uncertain.

4.5 Regionalisation

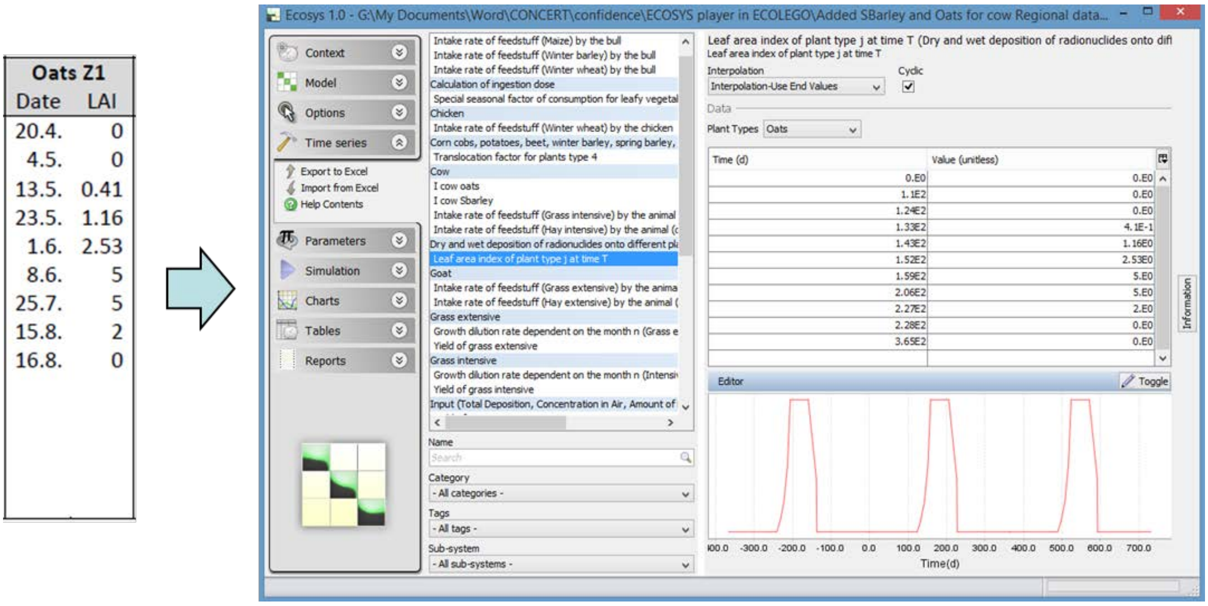
As examples, we have considered Norway and Spain to consider the impact regionalisation; these two countries have considerably different climates and farming practices.

Norway

Datasets relating to parameters of relevance to: (1) the growing season and harvest periods of crops and grass including seasonal development of LAI; and (2) animal feeding practice were collated in COMET and HARMONE reports (Thørring et al., 2016a; Staudt, 2016a, 2016b). These data for Norway have been incorporated within the FDMT model in ECOLEGO.

As noted above, Norway was categorised into three zones defined by growing season (Thørring et al., 2016a). The categorisation was essentially based on areas delineated by the time of year at which the average temperature exceeded 5^0C (Zone 1 = before 01/05; Zone 2 = 01/05 to 01/06 and Zone 3 = after 01/06). The crop types considered include cereals and vegetables, fruits and berries. These crop types are essentially limited to Zone 1 as their production would be unlikely in the other two zones. The details of which datasets have been incorporated in the model are given in Appendix 5. An example of the implementation is provided in Figure 4.

Grass yields are reported by Thørring et al. (2016a) for all three growing season zones in Norway; mountainous areas with short growing seasons are used as pasture for sheep and cows in the summer. The details of datasets incorporated used are given in Appendix 5.



Oats Z1	
Date	LAI
20.4.	0
4.5.	0
13.5.	0.41
23.5.	1.16
1.6.	2.53
8.6.	5
25.7.	5
15.8.	2
16.8.	0

Ecosys 1.0 - G:\My Documents\Word\CONCERT\confidence\ECOSYS player in ECOLEGO\Added SBarley and Oats for cow Regional data...

Intake rate of feedstuff (Maize) by the bull
Intake rate of feedstuff (Winter barley) by the bull
Intake rate of feedstuff (Winter wheat) by the bull
Calculation of ingestion dose
Special seasonal factor of consumption for leafy vegetal
Chicken
Intake rate of feedstuff (Winter wheat) by the chicken
Corn cobs, potatoes, beet, winter barley, spring barley,
Translocation factor for plants type 4
Cow
I cow oats
I cow Sbarley
Intake rate of feedstuff (Grass intensive) by the animal
Intake rate of feedstuff (Hay intensive) by the animal (c
Dry and wet deposition of radionuclides onto different pl
Leaf area index of plant type j at time T
Goat
Intake rate of feedstuff (Grass extensive) by the anima
Intake rate of feedstuff (Hay extensive) by the animal (
Grass extensive
Growth dilution rate dependent on the month n (Grass e
Yield of grass extensive
Grass intensive
Growth dilution rate dependent on the month n (Intensi
Yield of grass intensive
Input (Total Deposition, Concentration in Air, Amount of

Name: Search
Category: - All categories -
Tags: - All tags -
Sub-system: - All sub-systems -

Leaf area index of plant type j at time T (Dry and wet deposition of radionuclides onto diff
Leaf area index of plant type j at time T

Interpolation: Interpolation-Use End Values
Cyclic: ☑

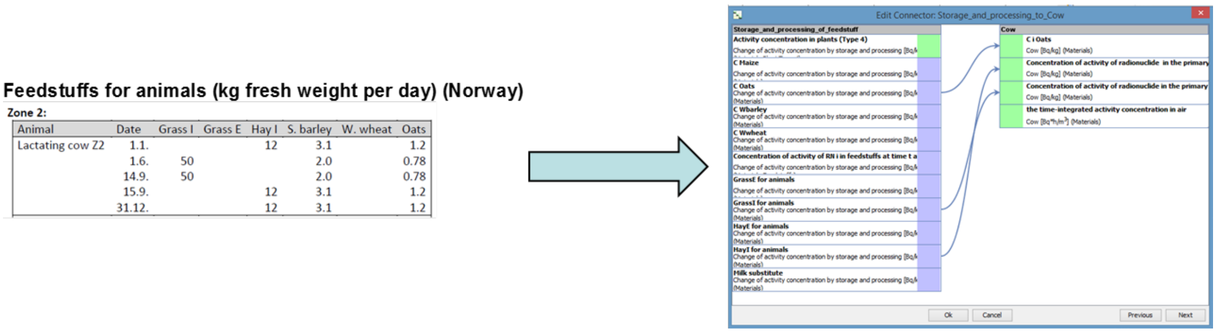
Data
Plant Types: Oats

Time (d)	Value (unitless)
0.E0	0.E0
1.1E2	0.E0
1.24E2	0.E0
1.33E2	4.1E-1
1.43E2	1.16E0
1.52E2	2.53E0
1.59E2	5.E0
2.06E2	5.E0
2.27E2	2.E0
2.28E2	0.E0
3.65E2	0.E0

Figure 4. LAI data from Thørring et al. (2016a): transformation for inclusion in the ECOLEGO implementation of FDMT.

Thørring et al. (2016a) noted that, in Norway, a minor but still considerable fraction of the milking cows are on rough mountain or 'outfield' (semi-natural pastures) grazing during summer and that for these animals the Grass E category is more relevant than Grass I. It is a relatively easy procedure to swap between these pasture categories (as a radionuclide ingestion source for cattle) in the ECOLEGO-FDMT implementation.

The data provided in the COMET project (Thørring et al., 2016a) in relation to feedstuffs for lactating cows included the addition of two feedstuffs – spring barley and oats. Incorporating this required a small structural alteration to the original model set-up (Figure 5).



Feedstuffs for animals (kg fresh weight per day) (Norway)

Zone 2:

Animal	Date	Grass I	Grass E	Hay I	S. barley	W. wheat	Oats
Lactating cow Z2	1.1.			12	3.1		1.2
	1.6.	50			2.0		0.78
	14.9.	50			2.0		0.78
	15.9.			12	3.1		1.2
	31.12.			12	3.1		1.2

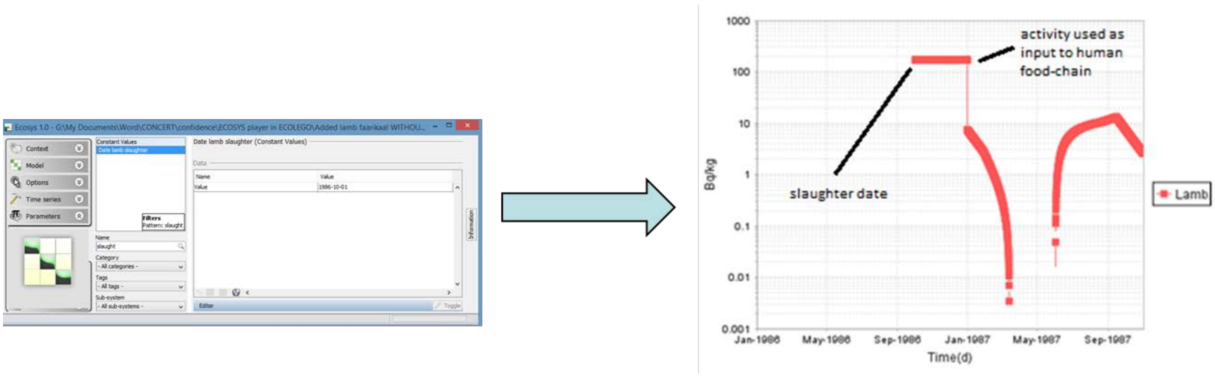
Edit Connector: Storage_and_processing_to_Cow

Storage_and_processing_of_feedstuff
- Activity concentration in plants (Type 4) – Change of activity concentration by storage and processing [Bq/k
- C Maize – Change of activity concentration by storage and processing [Bq/k
- C Oats – Change of activity concentration by storage and processing [Bq/k (Materials)
- C Wbarley – Change of activity concentration by storage and processing [Bq/k (Materials)
- C Wwheat – Change of activity concentration by storage and processing [Bq/k (Materials)
- Concentration of activity of RN i in feedstuffs at time t a – Change of activity concentration by storage and processing [Bq/k
- GrassE for animals – Change of activity concentration by storage and processing [Bq/k
- GrassI for animals – Change of activity concentration by storage and processing [Bq/k (Materials)
- HayE for animals – Change of activity concentration by storage and processing [Bq/k (Materials)
- HayI for animals – Change of activity concentration by storage and processing [Bq/k (Materials)
- Milk substitute – Change of activity concentration by storage and processing [Bq/k (Materials)

Cow
- C i Oats – Cow [Bq/kg] (Materials)
- Concentration of activity of radionuclide in the primary – Cow [Bq/kg] (Materials)
- Concentration of activity of radionuclide in the primary – Cow [Bq/kg] (Materials)
- the time-integrated activity concentration in air – Cow [Bq*h/m³] (Materials)

Figure 5. Data for feedstuffs for animals (Lactating cow in Z2) from Thørring et al. (2016a) and the primary structural change in the ECOSYS-87/FDMT-ECOLEGO model to account for this.

Thørring et al. (2016a) noted that there is a clear seasonality of lamb/sheep production in Norway. The lambs are born in March–May, released on mountain or outfield pastures during May–June and collected in September. The slaughter period is generally September–October (which provides most of the meat used for human consumption in the following year). Modifications have been made to the FDMT model structure in ECOLEGO to allow the user to select a date of lamb slaughter. This date is subsequently used to define the activity concentrations that are used as input to the calculation of human ingestion doses (Figure 6). In the Figure 6, the Cs-137 activity at the time of slaughter for lamb is used as the input value for subsequent (human ingestion dose) calculations and the activity concentration in lamb meat is kept constant over time in the following months up until the end of the first year (the assumption being that the lamb meat from the given slaughter date is used as a source of food for several months thereafter). Following the end of the first year the model simulations simply follow the activity concentrations in lamb meat that would have been present had the slaughter event not occurred. Subsequent slaughter dates (this of course being an annual event) have not currently been included in the model.


Ecosys 1.0 - G:\My Documents\Word\CONCERT\confidence\ECOSYS player in ECOLEGO\Added lamb faarikaal WITHOU...

Date lamb slaughter (Constant Values)

Name	Value
Value	1986-10-01

Filters
Pattern: slaught

Name: slaught
Category: - All categories -
Tags: - All tags -
Sub-system: - All sub-systems -

Figure 6. Representation of slaughter date for lamb in the ECOLEGO FDMT implementation and how the implementation of this value affects ^{137}Cs activity concentrations in lamb meat providing inputs to the first year of ingestion dose calculations (slaughter dates for subsequent years have not been considered in the model set up).

Spain

The Iberian Peninsula has a great variety of agro-climatic zones and in the case of the Mediterranean area there are many subcategories influencing the choice of model parameters for the crops produced.

As for Norway, the main sources of information for Spanish regionalisation of FDMT has come from the recent COMET and HARMONE projects (Thørring et al., 2016a, Staudt, 2016a, 2016b). The main parameters considered for Spanish regionalisation were: foodstuffs consumption rates, crop yields, harvesting periods, leaf area indices, feedstuffs and animal feeding regimes. For the first three, there are complete sets of national statistics values, and assumptions have been needed to adapt this extensive and detailed information to the database structure and set of parameters considered in FDMT (Thørring et al., 2106a). Information of the data used to parameterise the ECOLEGO implementation of FDMT can be found in Appendix 5.

Leaf Area Index data for the Spanish crops have been estimated from LAI normalised curves. The parameters describing the LAI normalised curves and the maximum LAI value for the crops considered in the study have been extracted from the plant growth database of the SWAT model (Arnold et al., 2013). Leaf area index time series were implemented for, winter and spring wheat, winter and spring barley, rye, maize and oats. For extensive and intensive grass LAI values were calculated according to (Müller & Pröhl, 1993) using a relationship between LAI and yield. For the grass and hay we introduced a growth dilution factor as used in JRodos, but shifting values forwards by one month (i.e. assume the JRodos default for March to the the April value for Spain etc.) (Thørring et al. 2016).

The Spanish National Crop Calendar for 1992 (MAPAMA, 1993) has been used to source data for sowing and harvesting dates. The calendar includes the distribution of the monthly mean percent of harvested and marketed production of each crop. For our purposes, the mean national data have been used to obtain representative values for sowing and harvesting dates and the mean growing period (days) of each crop or crop group.

Appropriate crop yields for Spain were taken from the National Agricultural Statistics (2014). These data are classified by crop type and for both dry and irrigated surfaces; seasonality is not considered. For the purposes of this assessment the mean dry yields at the national level have been used.

Feed resources for animals are set out in the national statistics (National Agricultural, Statistics 2014)) under the headings of forage crops, grassland, and grazed forest and shrub land. Depending on the feeding regime, we distinguished between intensive based production systems (indoor feeding, intensively managed pastures) and extensive productions systems utilising semi-natural pastures. The daily intake rates of feedstuffs throughout the year, have been estimated taking into account the nutritional needs of the animal-type, under each specific feeding regime, the distribution of the forage and grass production throughout the year and the stocking capacity of the grazing areas (Díaz Gaona et al., 2006; San Miguel Ayanz, 2006; Álvarez Sánchez-Arjona, 2010). For this study, we only considered cow milk and lamb production.

4.6 Probabilistic model runs

Using a Monte Carlo sampling method, 500 simulations were made for each run using the EGOLECO FDMT implementation using the parameter values as discussed in section 4.4 above (not the regionalised parameters from section 4.5). The choice of 500 iterations was based on practical considerations as the higher number of iterations required considerably longer simulation time. As already mentioned, upon updating of the FDMT default parameters, PDFs have been assigned to parameters whenever the underlying statistics were available (See Appendix 4). To illustrate the probabilistic simulation functionality, FDMT was applied to the scenarios described above (i.e. those used for the model testing considering wet and dry deposition cases); eighteen model runs were conducted. The resulting simulations are for cow milk, beef and lamb; dry and wet depositions and Sr-90, I-131 and Cs-137. For each run mean, 5th and 95th percentiles were simulated over a period of 5 years.

4.7 Sensitivity analyses

Sensitivity analysis can be defined as the study of how the variation in the output of a model (numerical or otherwise) can be apportioned, qualitatively or quantitatively, to different sources of variation, and how the given model depends upon the information fed into it (Saltelli et al. 2004). A related practice is uncertainty analysis, which has a greater focus on uncertainty quantification and propagation of uncertainty. Ideally, uncertainty and sensitivity analysis should be run in tandem.

It is important to note that the generic sensitivity analysis conducted in this report has a primary focus on providing proof of concept. There are significant limitations in undertaking an analysis of this type and special care should be taken in relation to the interpretation of results. For a start, not all parameters could be assigned probability distributions either for lack of underlying data or because they were not included in the model in a format that lent itself to such a characterisation. For example, many parameters that have a time dependency, e.g. LAI and grass biomass dilution rate are presented as time dependent tables in the model. Essentially, we are combining parameters from large regional (even global) datasets and therefore diligence should be paid to avoid over-interpretation of a general sensitivity analysis. Most notably there is a concern that values may be sampled from parameter distributions that might result in highly unlikely (potentially even impossible) combinations of parameter values. An example can be given in relation to soil to grass concentration ratios for Cs-137 and soil densities. If care is not taken in combining data correctly, data for low density soils (which are essentially characterised by organic soil in the underlying datasets) could be combined with Cs-137 CR data for higher density soils types, with textural classes such as sand, and for which transfer can be different. This may be mitigated, to some degree, by:

I. Careful sub-division of categories (i.e. model 'blocks'), a pertinent example being the separate treatment of Extensive pasture (where more organic soils with concomitant parameters predominate) and Intensive pasture (where more mineral soil might be considered more prevalent).

II. Introducing correlations between parameters that are known to be closely associated so that unrealistic combinations are excluded. Although no attempt has currently been made to specify correlations, though this the functionality exists in ECOLEGO, there are numerous parameters in ECOSYS-87/FDMT that would be expected to be correlated. An example can be given by the inverse relationship between the radionuclide migration rate in soil, λ_{ai}, and the depth of the rooting zone e.g. L_{arable} or $L_{pasture}$ (since the one is derived from the other).

However, the limitations of the analysis cannot be completely removed.

Several sensitivity analysis methods of varying degree of complexity have been proposed in the literature (Saltelli et al. 2004):

- Graphical methods – visualise input-output relationships, for example using scatter-plots.
- Screening methods – used to find which parameters have the highest effect on the uncertainty in predictions for outputs of interest and which can be set to nominal values, without loss of information about the variance of the output.
- Linear regression and correlation methods – Provide quantitative measures of input-output relationships, but are only applicable to monotonic relationships between inputs and outputs.
- Variance based methods – Provide estimates of the proportion of variance of the output that is explained by a given parameter. These methods are model independent, but are often computationally expensive.

The choice of an appropriate method depends on several factors, such as the type of dependency between the inputs/parameters and the simulation endpoints of interest, the time needed for performing a model simulation and the number of uncertain parameters.

For monotonic dependencies between inputs and outputs, simple methods based on correlations, such as the Pearson Correlation Coefficient and the Spearman Rank Correlation Coefficient are often sufficient; whereas for non-monotonic dependencies more advanced methods, based on decomposition of the variance, are required.

Variance based methods are universal methods that can be applied to any type of model. There exist several variance-based methods available in the literature, such as the Extended Fourier Amplitude Sensitivity Test (EFAST) described in (Saltelli, 1999) and the Sobol method (Sobol, 1990). These methods can calculate first and higher order sensitivity indexes by making use of specialised sampling procedures, but usually require a large number of samples, which might result in long simulation times (computationally expensive methods) depending on the time required for one model simulation. In recent years, an alternative variance-based method, called the Effective Algorithm for Global Sensitivity Indices or EASI method (Plischke, 2009), has been developed, that can yield first and second order sensitivity indexes from an ordinary probabilistic simulation, i.e. by Monte Carlo or Latin Hypercube sampling methods.

All sensitivity analysis methods presented above are available in ECOLEGO and are described in the ECOLEGO Online User Guide (http://ecolego.facilia.se/ecolego/show/ECOLEGO+wiki). The Sensitivity Analysis Toolbox has been applied in this work, although there are other ways of performing sensitivity analyses in ECOLEGO.

The sensitivity analysis in this work has its basis in the case study described above for the wet deposition scenario and considers the same endpoints of radionuclide activity (^{90}Sr, ^{131}I and ^{137}Cs) concentrations in winter wheat (whole grain), Leafy vegetables, Cow milk, Cow meat and Lamb meat. The simulation period was extended to explore the influence of some parameter we expected only to come ‘into play’ after a prolonged period and various time points were selected, namely : 1 day, 1 week, 2 weeks, 1 month, 2 months, 1 year, 10 years, 25 years, to account for the dynamics of the system. We were aware that the sensitivity of the model output to any given parameter will have a time dimension so selected multiple time points to encompass this. The following approach was taken:

1. Probabilistic simulations – 5000 iterations by Monte Carlo sampling (random sampling) from the probability distributions assigned to a number of model parameters.
2. The probabilistic results were used for calculating different correlation and regression coefficients for the untransformed and ranked variables (this means that model inputs and outputs are ranked).
3. The EASI method was applied. This variance decomposition method is considered to be model independent. The calculated sensitivity index for each uncertain parameter represents the contribution of this parameter to the variance of the output.

In principle, for this study the EASI method alone was sufficient for ranking the model parameters by sensitivity, but it does not show if the parameter has a positive or negative effect on the output. On the other hand, although The Spearman Rank Correlation Coefficients do not give a quantitative measure of the contribution of the parameters to the variance of the outputs, they show the direction of the effect of the parameters on the output of interest. The results from both analyses have therefore been used in tandem when presenting the results.

5 Results from analysis and discussion

5.1 Wet deposition scenario: inter-comparison old versus new

Examples of results from model simulations using the old (ECOSYS-87/FDMT in EXCEL) and new (ECOSYS-87/FDMT in ECOLEGO) systems and the same original default parameters are given below. In Figure 7, ^{137}Cs activity concentrations in different foodstuffs for the wet deposition scenario described above are presented.

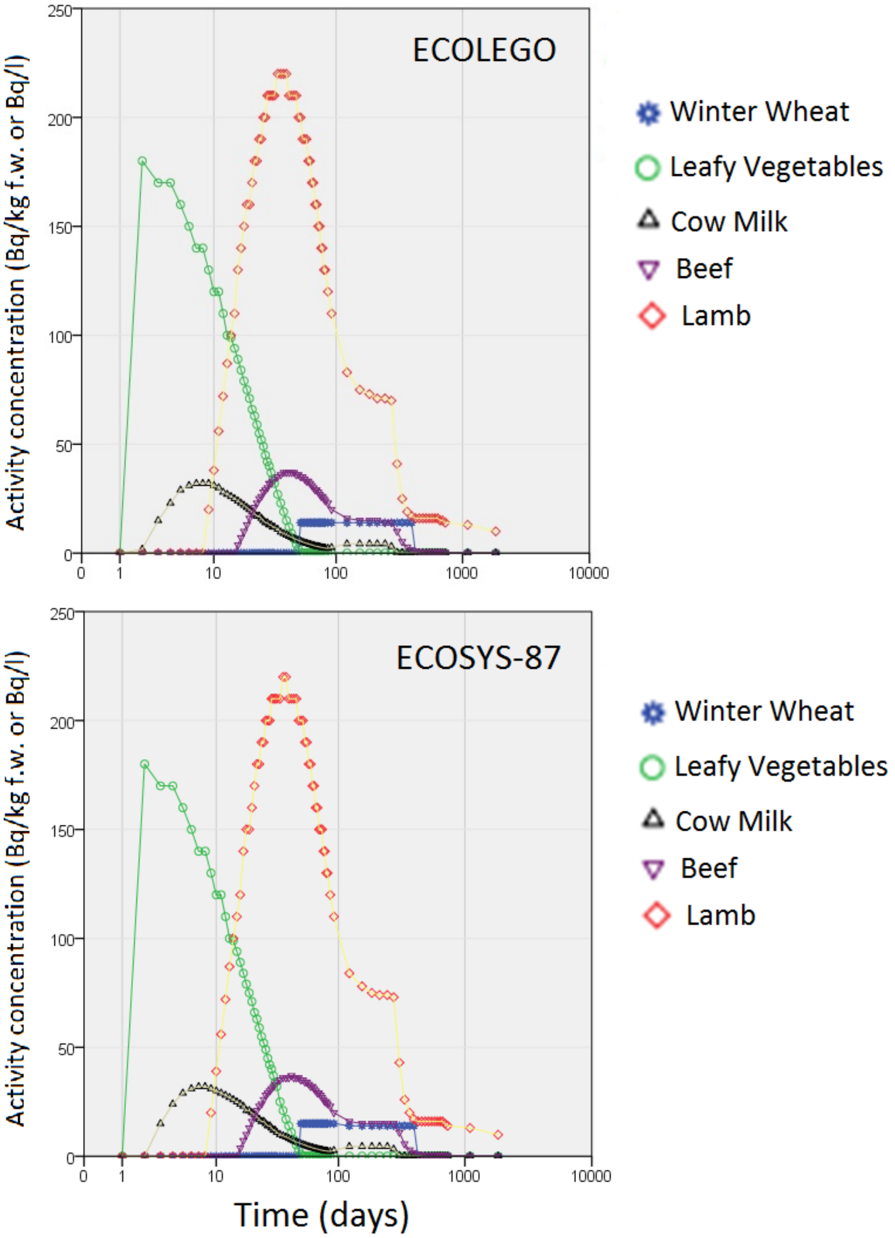


Figure 7. Cs-137 concentration in foodstuffs obtained with ECOLEGO and ECOSYS-87 for the wet deposition scenario

Differences between the model outputs from ECOLEGO and ECOSYS-87 are difficult to discern from a cursory visual inspection of the figures presented and the correspondence between the old model and new implementation is reassuringly close. Minor differences do exist in a limited number of cases (Table 8) though at worst the deviation is no greater than approximately 7 %.

Table 8. Cs-137 concentrations in foodstuffs predicted for the wet deposition scenario.

Foodstuff	**Maximum concentration (Bq/kg)**		**Concentration at the end of 5-years period (Bq/kg)**	
	ECOSYS-87 EXCEL	**ECOLEGO**	**ECOSYS-87 EXCEL**	**ECOLEGO**
Winter wheat	15	14	3.5E-2	3.5E-2
Leafy vegetables	180	180	2.8E-2	2.8E-2
Cow`s milk	32	32	4.6E-2	4.6E-2
Beef cow	37	37	1.5E-1	1.6E-1
Lamb	220	220	9.9	10

5.2 Dry deposition scenario: inter-comparison old versus new

In Figure 8, ^{90}Sr activity concentrations in different foodstuffs for the dry deposition scenario described above are presented; Table 9 presents maximum and 5 year predictions. As for the wet deposition scenario, the predictions of the two model implementations are virtually the same.

Table 9. Sr-90 concentrations in foodstuff for the dry deposition scenario.

Foodstuff	**Maximum concentration (Bq/kg)**		**Concentration at the end of 5-years period (Bq/kg)**	
	ECOSYS-87 EXCEL	**ECOLEGO**	**ECOSYS-87 EXCEL**	**ECOLEGO**
Winter wheat	32	32	4.1E-1	4.1E-1
Leafy vegetables	490	490	6.5E-1	6.5E-1
Cow`s milk	38	39	3.2E-1	3.2E-1
Beef cow	1.4	1.4	4.8E-2	5.0E-2
Lamb	1.3	1.3	5.3E-2	5.3E-2

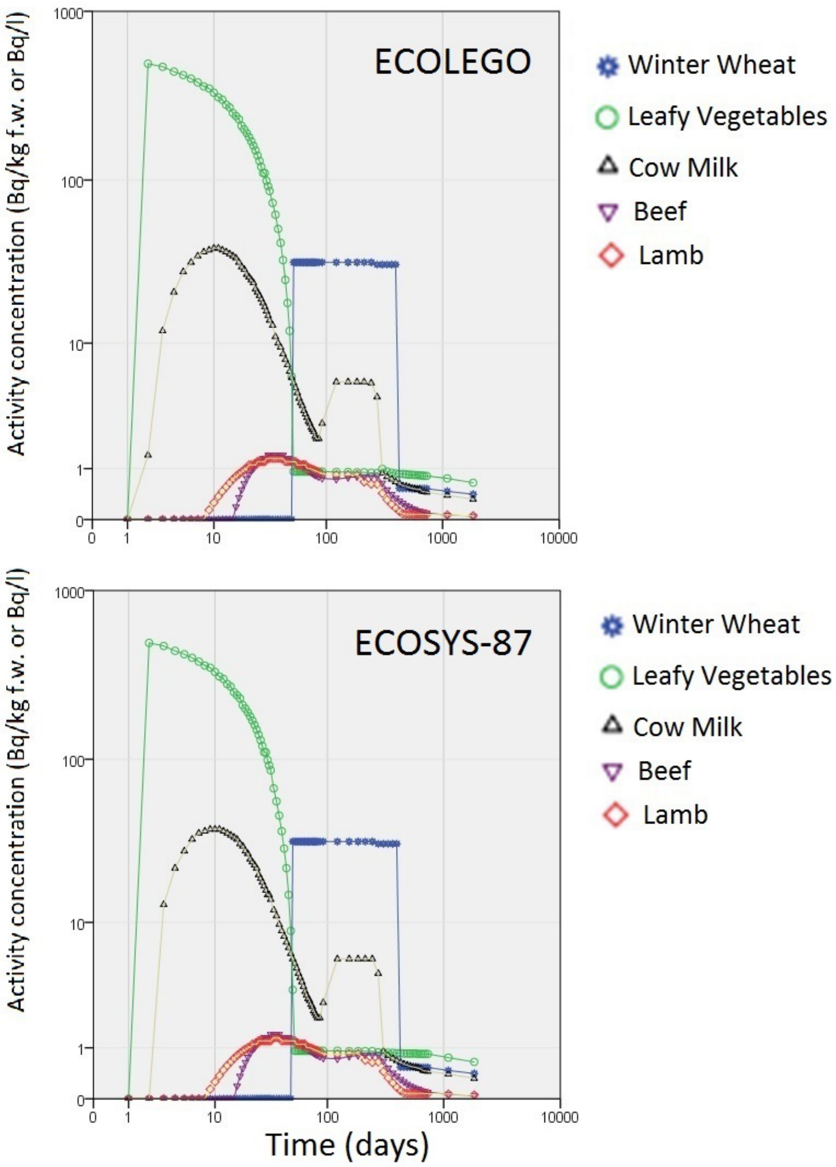


Figure 8. Sr-90 concentration in foodstuffs obtained with ECOLEGO and ECOSYS-87 for the dry deposition scenario.

5.3 Old versus new/updated parameters – (deterministic) model output comparison

To evaluate the impact of parameter updating, FDMT was applied to the test scenarios described earlier by running the model deterministically. Activity concentrations in selected food products derived in applying both the old and new default parameter values in FDMT are presented in Tables 10-13. The largest changes, in terms of the maximum value derived appear to be associated with predictions for the animal products.

Table 10. Maximum activity concentrations (Bq/kg) estimated for wet deposition scenario based on using both old default and new updated parameter values in FDMT.

	Cs-134		**Cs-137**		**Sr-90**		**I-131**	
	Old	***Updated***	**Old**	***Updated***	**Old**	***Updated***	**Old**	***Updated***
Winter wheat	14	*14*	15	*15*	20	*20*	0.1	*0.1*
Leafy vegetables	181	*181*	181	*181*	274	*274*	95	*94*
Cow`s milk	32	*46*	32	*46*	32	*23*	17	*26*
Beef (cow)	35	*74*	36	*75*	1	*12*	0.06	*4*
Lamb	208	*305*	214	*312*	1	*3*	0.08	*4*

In some cases, as exemplified by Sr-90 and I-131 in Beef (cow) and Lamb meat, the increase in the maximum activity concentrations derived when using updated compared to old default parameters is considerable. In the most extreme case (I-131 in Beef (cow)), the model runs using updated parameters yield activity concentration approximately 70 times greater than those using old parameters.

At the end of 5 years, all activity concentrations derived for the selected food products are relatively low and, with the exception of Lamb, are at levels below 1 Bq/kg. At this stage, of course, I-131 has essentially decayed from the system and is, therefore, not reported further.

Table 11. Activity concentrations (Bq/kg) at the end of simulation time (5 years) estimated for wet deposition scenario based on using both old default and new updated parameter values in FDMT.

	Cs-134		**Cs-137**		**Sr-90**	
	Old	***Updated***	**Old**	***Updated***	**Old**	***Updated***
Winter wheat	7.3E-3	*1.2E-2*	3.5E-2	*4.7E-2*	4.0E-1	*2.0E-1*
Leafy vegetables	5.8E-3	*3.0E-3*	2.8E-2	*1.1E-2*	6.0E-1	*1.6E-1*
Cow`s milk	9.7E-3	*1.8E-2*	4.6E-2	*8.6E-2*	3.0E-1	*1.7E-1*
Beef (cow)	2.9E-2	*4.9E-2*	1.6E-1	*2.3E-1*	5.0E-2	*1.8E-1*
Lamb	2.0E+00	*1.7E+00*	1.0E+01	*8.4E+00*	5.0E-2	*5.0E-2*

Although food products generally exhibit a relatively elevated contamination level, the pattern observed for the outputs (maximum values) from the dry deposition scenario is essentially the same as that observed for the wet deposition scenario. Maximum activity concentrations in crops are essentially unaffected by the parameter update whereas activity concentration in animal products can, in some cases, exhibit considerable changes.

Table 12. Maximum activity concentrations (Bq/kg) estimated for dry deposition scenario based on using both old default and new updated default parameter values in FDMT.

	Cs-134		**Cs-137**		**Sr-90**		**I-131**	
	Old	***Updated***	**Old**	***Updated***	**Old**	***Updated***	**Old**	***Updated***
Winter wheat	37	*37*	39	*39*	32	*32*	2	*2*
Leafy vegetables	487	*487*	487	*487*	487	*487*	1560	*1555*
Cow`s milk	64	*93*	64	*94*	38	*27*	226	*346*
Beef (cow)	71	*149*	73	*152*	1	*14*	1	*49*
Lamb	416	*613*	427	*628*	1	*3*	1	*58*

Similarly at the end of the simulation period of 5 years, changes can be seen in the outputs from the dry deposition model runs for all categories of foodstuffs albeit at levels that are relatively low compared to those observed in the early phase post deposition.

Table 13. Activity concentrations (Bq/kg) at the end of simulation time (5 years) estimated for wet deposition scenario based on using both old default and new updated parameter values in FDMT.

	Cs-134		**Cs-137**		**Sr-90**	
	Old	***Updated***	**Old**	***Updated***	**Old**	***Updated***
Winter wheat	7.5E-3	*1.3E-2*	3.6E-2	*4.8E-2*	4.0E-1	*2.0E-1*
Leafy vegetables	5.9E-3	*3.1E-3*	2.8E-2	*1.1E-2*	4.0E-1	*1.6E-1*
Cow`s milk	9.8E-3	*1.8E-2*	4.7E-2	*8.8E-2*	6.0E-1	*1.7E-1*
Beef (cow)	3.0E-2	*5.0E-2*	1.6E-1	*2.4E-1*	3.0E-1	*1.8E-1*
Lamb	2.0E+00	*1.8E+00*	1.0E+01	*8.5E+00*	5.0E-2	*6.0E-2*

5.4 Regionalisation

Simulations for the dry deposition scenario specified above (taking 1 kBq/m^2 ^{137}Cs as an example) result in predictions of changes in activity concentrations with time in selected foodstuffs; results for Norway and Spain are presented below.

Norway

The comparison between model outputs for winter wheat and leafy vegetables using the original default parameters (from Müller and Pröhl, 1993) and outputs derived from the updated regional parameters for Norway and including new (generic) radioeoclogical (element-dependent) parameters are presented in Figure 9.

The ^{137}Cs activity concentrations with time in leafy vegetables predicted using updated regional parameters are quite similar to those predicted using the original default. In contrast, the use of regional and updated generic parameters resulted in substantially higher ^{137}Cs levels in winter wheat compared to corresponding values derived using parameter defaults with a slight temporal shift relating to when activity concentrations become elevated. The degree of elevation in this cereal crop, due to using regional values, is consistent with the observations in the COMET project by Søvik et al. (2017). The authors in that study noted that comparison of runs with FDMT using default and Norwegian updates showed that levels of Cs-137 in winter (or spring) wheat were 2–4 times higher using the regionalised parameters. The implication from this is that element-independent parameters such as LAI (versus time), growing and harvesting regimes, are predominant in accounting for the differences observed between the default and regional-based ^{137}Cs activity concentrations in winter wheat for the initial period post deposition, at least. The updated radioecological parameters, which are not incidentally specific to Norway, appear to have limited influence in affecting the output. The radioecological parameters that were updated and which have a potential impact on cereal activity concentrations are limited to factors, such as soil to plant transfer factors and rate constants determining radionuclide behaviour in soils, these would not be expected to play an important role, with respect to determining contamination of foodstuffs, in the initial period (weeks and months) following an accident (when interception and subsequent loss rates will dominate).

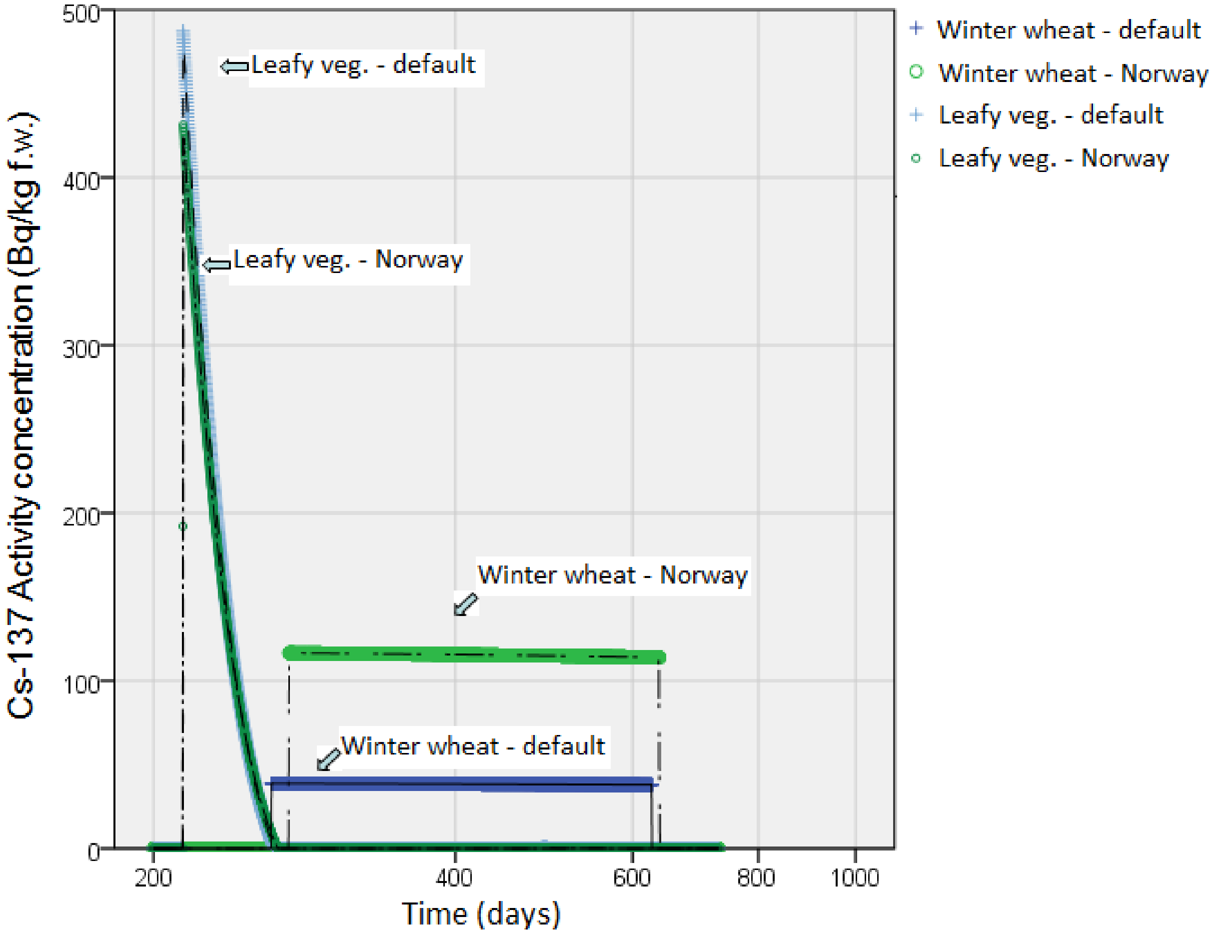


Figure 9. ^{137}Cs activity concentration (Bq/kg FM) versus time (from simulation start) following a dry deposition scenario for Winter wheat (regionalised parameters for Norway versus ECOSYS/FDMT default) and Leafy vegetables (regionalised parameters for Norway versus ECOSYS/FDMT default).

The comparison between model outputs for ^{137}Cs in milk using the original default parameters and outputs derived from the updated regional parameters for Norway and generic radioecological parameters are presented in Figure 10.

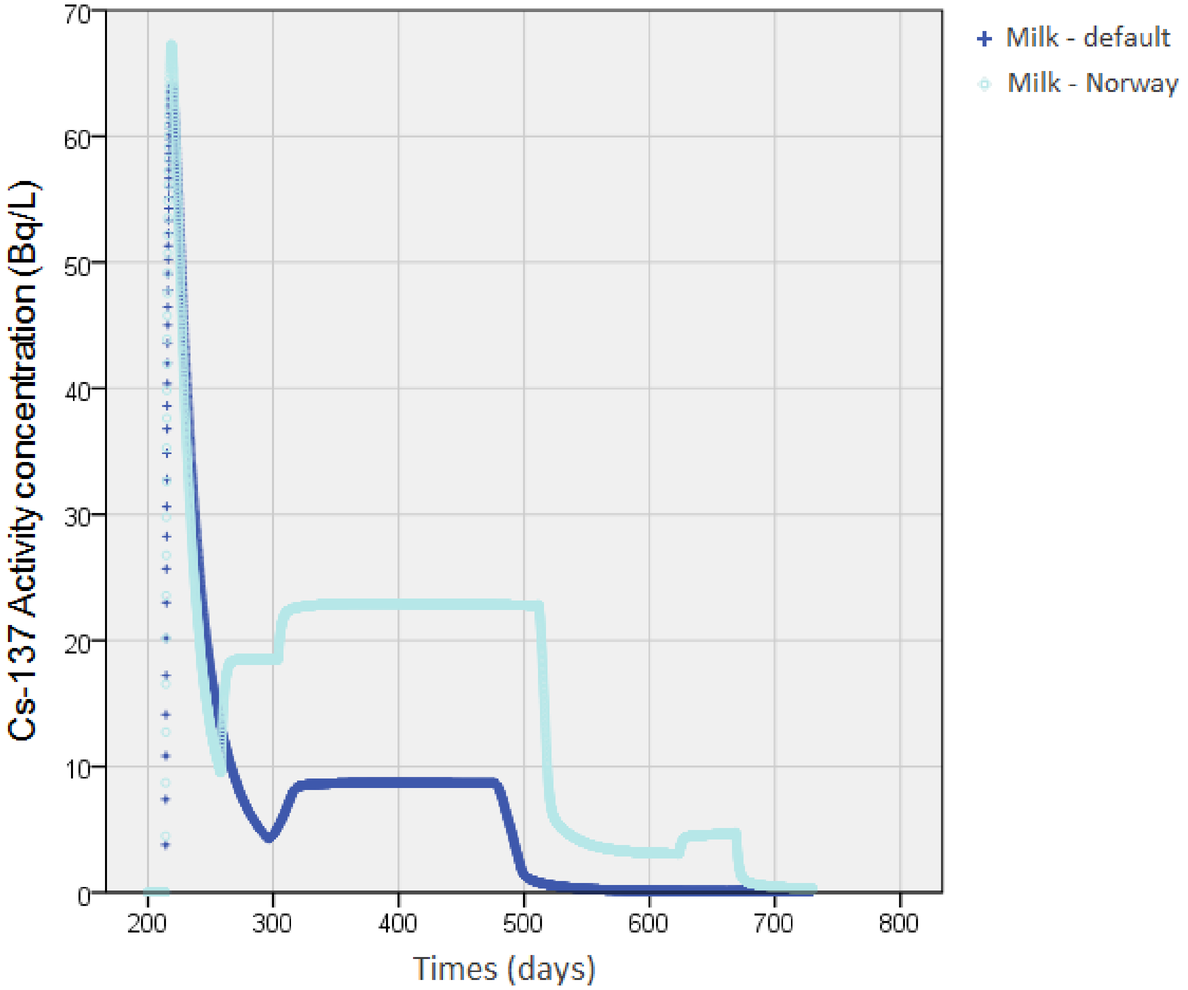


Figure 10. ^{137}Cs activity concentration (Bq/L) versus time (from simulation start) following a dry deposition scenario for cow milk (regionalised parameters for Norway versus default).

The ^{137}Cs activity concentrations in milk associated with regional (encompassing Norwegian-specific agricultural practices and grass growing conditions etc.) and updated (generic radioecological) parameters are substantially elevated above the ^{137}Cs levels in milk associated with default model runs for the period post 2 months from the time of deposition (1st August for the given case). This is in fact in contrast to the COMET analysis (Søvik et al., 2017) where results for ^{137}Cs levels cow milk were slightly lower using regionalised parameters compared to the defaults (i.e. predictions using Norwegian parameters were 70% of those using the default). For this particular case, the updated element-dependent/radioecological parameters (which for cow milk will include, soil to grass transfer factors, feed to animal transfer coefficients and updated information on biological half-lives) are likely playing a more influential role in determining milk concentrations than the element-independent parameters (e.g. the difference in milk transfer coefficient is sufficient to explain the comparative results). Nonetheless, the regionalised (for Norway) ECOLEGO version of the model has not been rigorously quality assured and there may be other reasons explaining the discrepancy. For example, grass growth dilution factors have not been modified in the regional set-up using ECOLEGO to account for the shorter growing season. This will undoubtedly result in a mismatch between the combination of parameters in calculating food-chain transfer to milk and will require further consideration in the future.

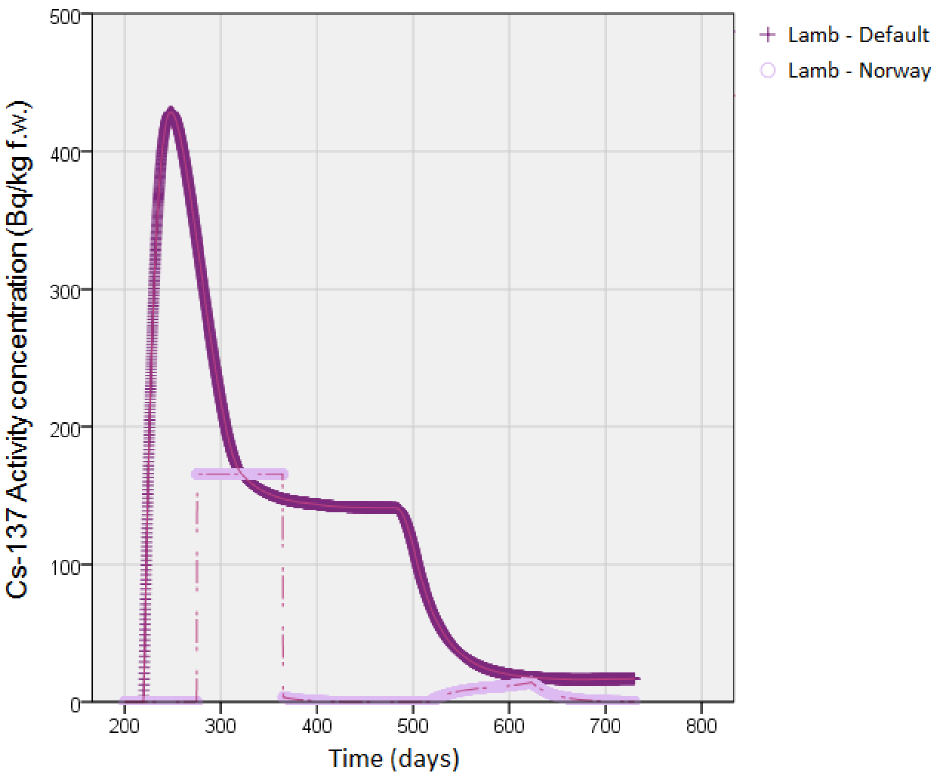


Figure 11. ^{137}Cs activity concentration (Bq/kg FM) versus time (from simulation start) following a dry deposition scenario for Lamb meat (regionalised parameters for Norway versus default).

Making a comparison between ^{137}Cs activity concentrations in lamb associated with model runs using regional/updated parameters and ^{137}Cs levels in lamb using default parameters is confounded by the substantial change made in the way that lamb is being considered for human consumption in the regionalised model set up. For the regional model run (Figure 11) a slaughter time was selected as 1st October and the activity concentration in lamb meat at this time was then defined as the relevant input for human ingestion dose calculations. The form of the profiles defining the changes in ^{137}Cs levels in meat over time are, therefore, quite different depending on whether the default or regionalised settings are used. The regionalised set up suggests (quite logically) that ^{137}Cs activity concentrations in lamb meat would not constitute a source of contamination to the human food-chain until a period after the date of slaughter. After this time, regional lamb meat would initially have a substantially lower ^{137}Cs level than the one derived using the default setting but at a later stage (within a few months) the regional levels would slightly exceed the default-derived predictions. As for milk, the regionalised model set up requires further quality assurance but the results are at least indicative of how the introduction of a slaughter time might alter the prediction of the dynamics of contamination levels in meat available for consumption. It is apparent, for example, that the period for which lamb meat is available for human consumption should be extended to the entire first year until the next slaughter date and not have a cut-off at one year from the simulation start date as the model is currently configured. This will be adjusted in the future.

Spain

In the following the terms 'Default', 'Spain+Default' and 'Spain+New' are used to describe results obtained using FDMT/ECOSYS-87 parameters alone, FDMT/ECOSYS-87 radioecological parameters with Spanish regionalisation parameters, and Spanish regionalisation parameters with updated radioecological parameters as presented in Appendix 4 (and discussed in Section 4). Table 14 summarises maximum activity concentation predictions for winter wheat, leafy vegetables, cow milk and beef together with predictions five years after deposition using the three different parameter combinations.

Table 14. Caesium-137 concentrations in foodstuffs predicted for the dry deposition scenario using different parameter implementations.

Foodstuff	Maximum concentration (Bq/kg)			Concentration 5-years after deposition (Bq/kg)		
	Default	Spain+Default	Spain+New	Default	Spain+Default	Spain+New
Winter wheat	39	4.1E-2	6.4E-2	3.6E-2	2.7E-2	4.2E-2
Leafy vegetables	467	62	62	2.8E-2	2.1E-2	9.2E-3
Cow`s milk	65	98	135	4.7E-2	4.5E-2	1.1E-1
Beef	75	114	226	1.6E-1	1.5E-1	3.0E-1

For leafy vegetables and especially cereals the maximum activity concentration predictions using the default FDMT/ECOSYS-87 parameters are considerably higher than predictions using Spanish regionalisation parameters. This demonstrates the potential importance of the non-radiological parameters especially soon after a deposition event. The assumed scenario depostion date (1st August) means that winter wheat has already been harvested and hence using the regionalised parameters the maximum activity concentrations are soley due to root uptake (i.e. no direct deposition etc.) in the subsequent years crop; the default values assume harvesting in the year of deposition.

For milk and beef the highest maximum activity concentrations are predicted for the model runs using Spanish regionalised parameters (Figure 12 presents predictions for beef). This is the consequence of assumed feeding regimes.

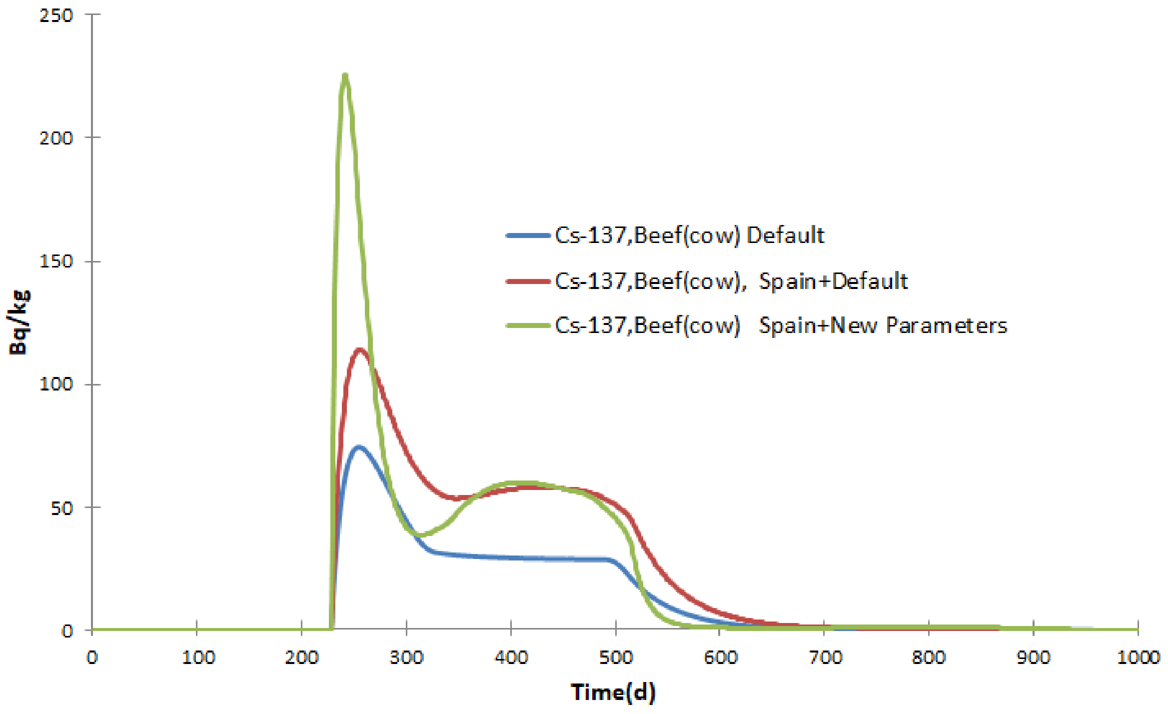


Figure 12 Caesium-137 activity cncentration predictions (Bq/kg FM) for beef in Spain.

5.5 Probabilistic simulations

Probabilistic simulations are an essential step in the process of uncertainty and sensitivity analyses. By implementing ECOSYS-87/FDMT in the ECOLEGO modelling platform we are able to conduct such analyses. For illustration purposes some of the results from the probabilistic runs are shown below, (Figures 13-15; Tables 15-17) for dry deposition scenarios. Results from wet deposition scenarios are provided in Appendix 6.

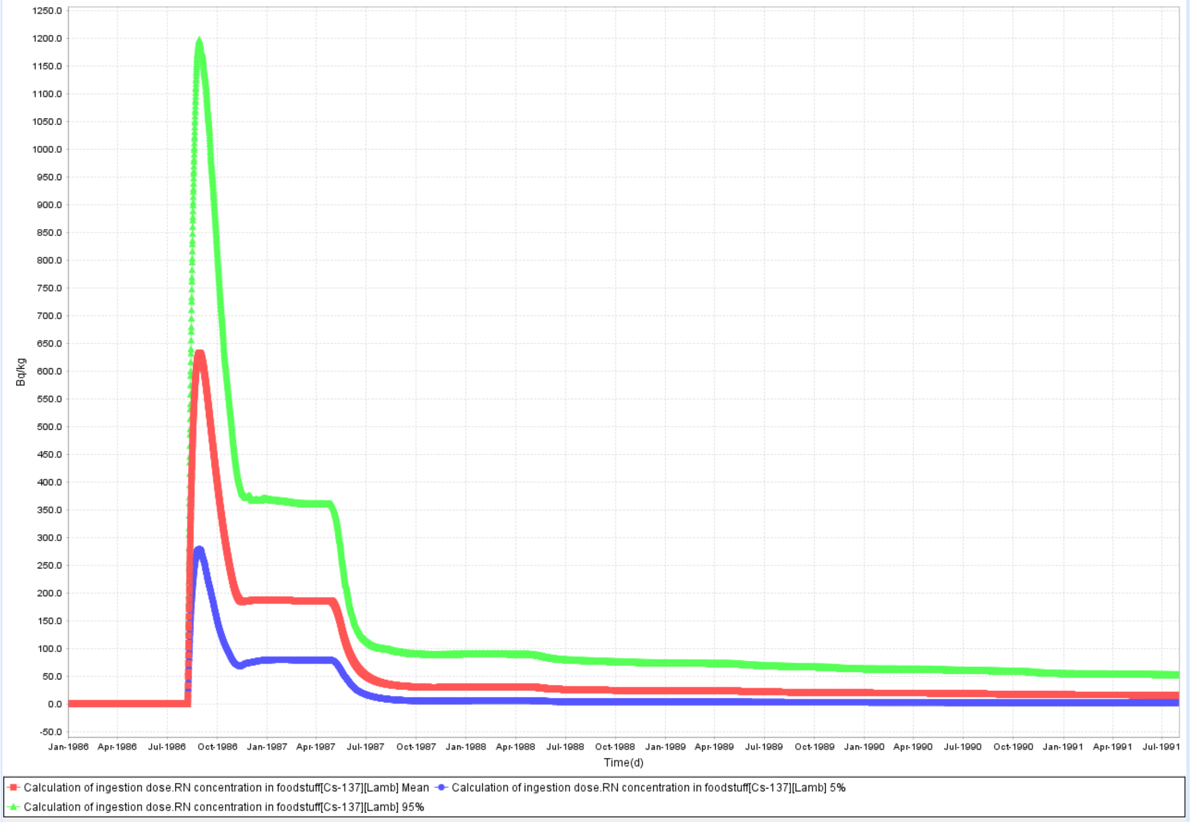


Figure 13. Probabilistic simulation of activity concentration of Cs-137 in lamb for dry deposition scenario. 5th percentile (blue), mean (red) and 95th percentile (green).

Table 15. Statistics for activity concentration of Cs-137 in lamb for dry deposition scenario at day 245 (32 days after initial deposition) when levels are approximately at a maximum.

Statistics	**Lamb, Cs-137 (Bq/kg)** **Dry deposition (245 d after the start of simulation)**
Mean	626
Std. Deviation	293
5%	273
Median	564
95%	1175

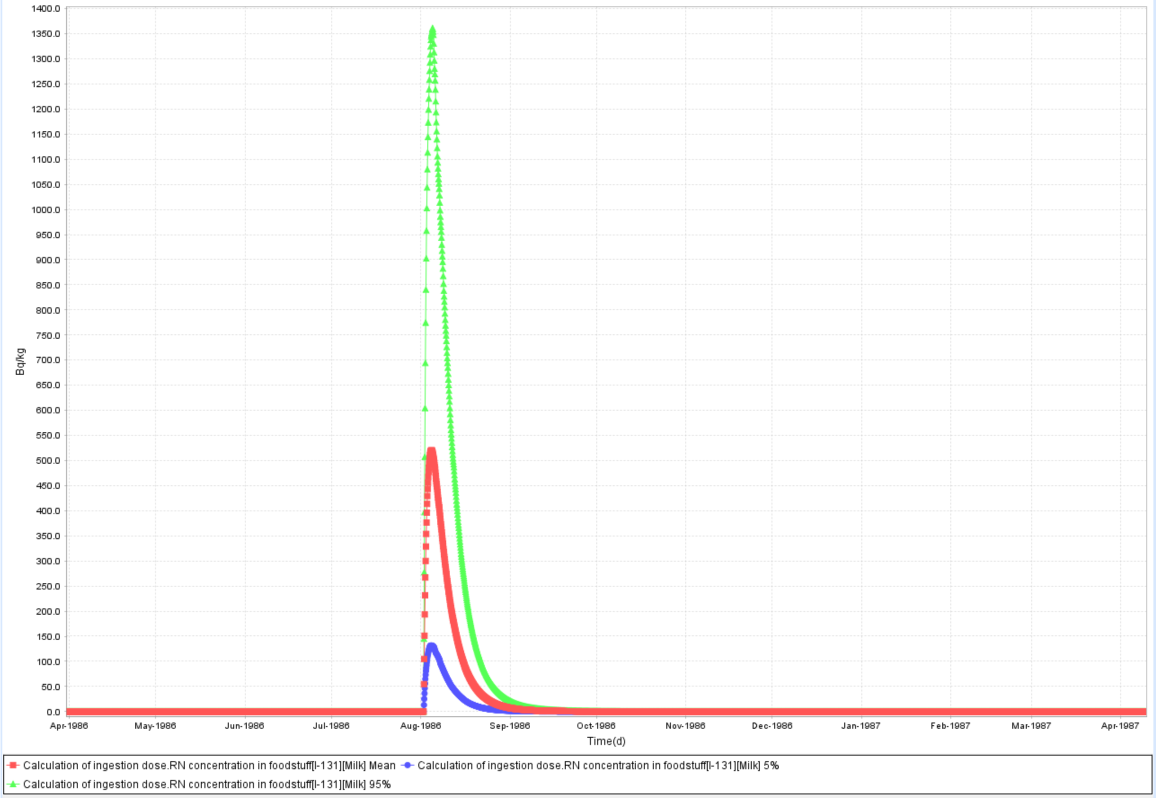


Figure 14. Probabilistic simulation of activity concentration of I-131 in cow milk for dry deposition scenario. 5th percentile (blue), mean (red) and 95th percentile (green).

Table 16. Statistics for activity concentration of I-131 in cow milk for dry deposition scenario at day 217 (4 days after initial deposition).

Statistics	**Cow Milk, I-131 (Bq/kg)** **Dry deposition (217 d after the start of simulation)**
Mean	553
Std. Deviation	419
5%	141
Median	455
95%	1309

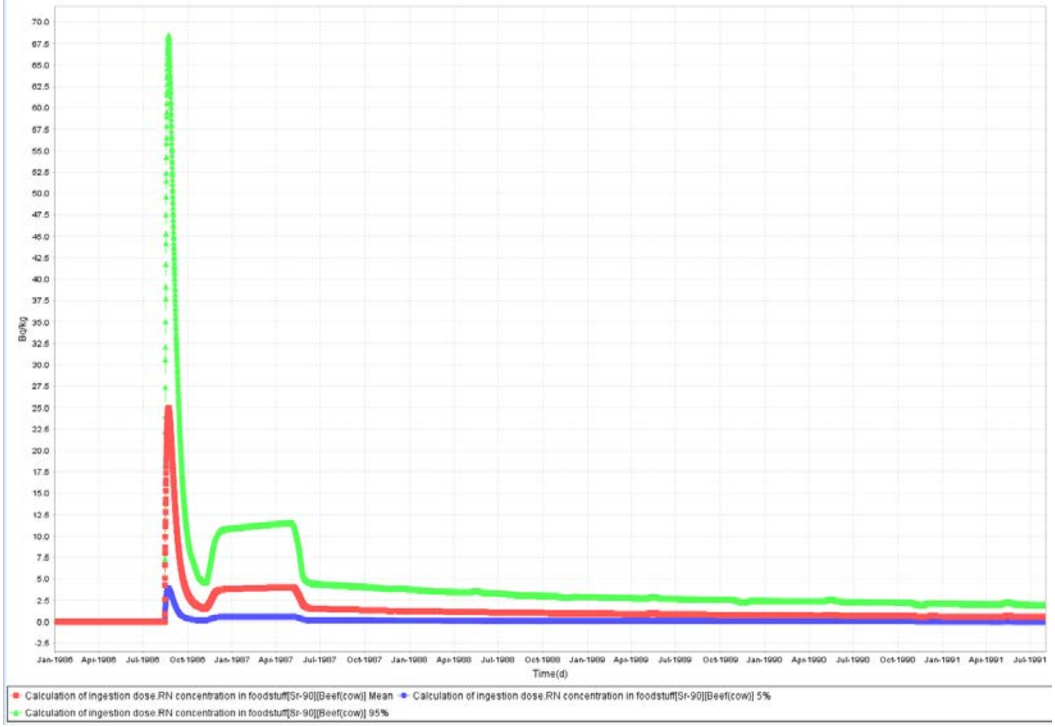


Figure 15. Probabilistic simulation of activity concentration of Sr-90 in beef (cow) for dry deposition scenario. 5th percentile (blue), mean (red) and 95th percentile (green).

Table 17. Statistics for activity concentration of Sr-90 in beef (cow) for dry deposition scenario at day 235 (22 days after initial deposition).

Statistics	**Cow Beef, Sr-90 (Bq/kg)** **Dry deposition (235 d after the start of simulation)**
Mean	21
Std. Deviation	21
5%	4
Median	15
95%	65

As seen from the outputs of probabilistic runs, the span between 5th and 95th percentiles is relatively narrow; the ratio of the 95th to 5th percentile falls generally around 10 and up to two-orders of magnitude at the most. The parameter uncertainty introduced from this analysis is essentially 'workable' in the sense that the results remain suitably constrained and something sensible can still be expressed regarding the output. Should the span between 5th and 95th percentiles have been much larger, e.g. the 95th to 5th percentile ratio reaching many orders of magnitude, problems may arise is specifying anything concrete when making a prognosis; at the low end of the prediction impacts might be negligible whereas at the high end, impacts may be dramatic. Nonetheless, the rather limited uncertainties observed in these simulations do not reflect the overall uncertainties associated with estimated concentrations but only uncertainties related to the limited number of parameters that have been considered in these runs. The number of parameters with a PDF, which can be included in probabilistic runs, is limited and differs for different the radionuclides and food products considered. For instance, while a probabilistic run for cow products and Cs-137 includes 22 parameters with associated PDFs, a run for lamb and I-131 includes only 11 parameters. It is important to have these considerations in mind when analysing estimated uncertainties of outputs of probabilistic runs.

5.6 Sensitivity analysis

Generally speaking, coefficients of determination (R^2) were close to unity for the ranked variables, for the various considered food products, as shown in the probabilistic summary statistics in the figures below. This indicates that there is a monotonic relationship between inputs and outputs. In many cases the coefficient of determination for the untranformed variables was low, which indicates that there is non-linearity in the relationship between inputs and outputs. When the EASI method was applied on ranked variables, the sum of the sensitivity indexes was close to one for all of the analysed cases.

Cs-137 Leafy vegetables

Results for the sensitivity analyses for ^{137}Cs in leafy vegetables are shown in Figures 16 and 17 for the wet deposition scenario defined above.

Parameter	1 day	1 week	2 weeks	1 month	2 months	1 year	10 years	25 years
Median	0,0E+00	1,3E+02	7,7E+01	1,7E+01	5,6E-02	5,1E-02	1,1E-02	9,7E-04
Std. dev.	0,0E+00	5,8E+01	3,9E+01	1,3E+01	1,2E-01	1,2E-01	3,4E-02	8,5E-03
5%	0,0E+00	2,2E+01	1,2E+01	2,5E+00	1,3E-02	1,2E-02	1,8E-03	5,6E-05
95%	0,0E+00	2,1E+02	1,4E+02	4,5E+01	3,0E-01	2,8E-01	7,4E-02	1,6E-02
R^2	0,00	0,91	0,89	0,80	0,71	0,57	0,60	0,40
R^2 ranked	0,00	0,97	0,93	0,89	0,95	0,89	0,92	0,92

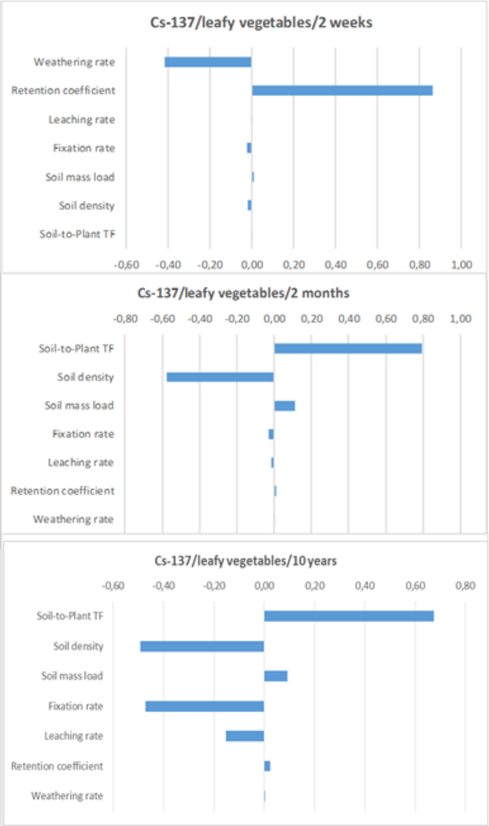


Figure 16. Cs-137 leafy vegetables : (i) Probabilistic summary statistics and (ii) Spearman rank correlation coefficients between parameters and output, for various time points.

The results from the analysis intuitively make sense. In the initial period of the simulation, up to the first month or so, the retention coefficient and (loss from vegetation) weathering rate constitute those parameters which predominate in terms of their contribution to the variance observed in ^{137}Cs activity concetrations in leafy vegetables. The information provided from the Spearman rank correlation coefficients illustate that, whereas the retention coefficient has a positive correlation with the assessment endpoint, the correlation with weathering rate is an inverse one. A corollary being that an increase in weathering rate will lead to a decrease in the simulated levels of ^{137}Cs in leafy vegetables. From a period of 2 months and extending in time up to the end of the simulation at 25 years, the soil to plant transfer factor (i.e. concentration ratio, F_v) becomes an important factor. This general trend was not unexpected, root uptake is know to become a dominant process at later periods post deposition, but this parameter appears to play a defining role earleir than perhaps expected. In the late stages of the simulation, 10 to 25 years, the uncertainties associated with processes influencing the behaviour of ^{137}Cs in soil will start to have a major influence upon the variance observed in the model output.

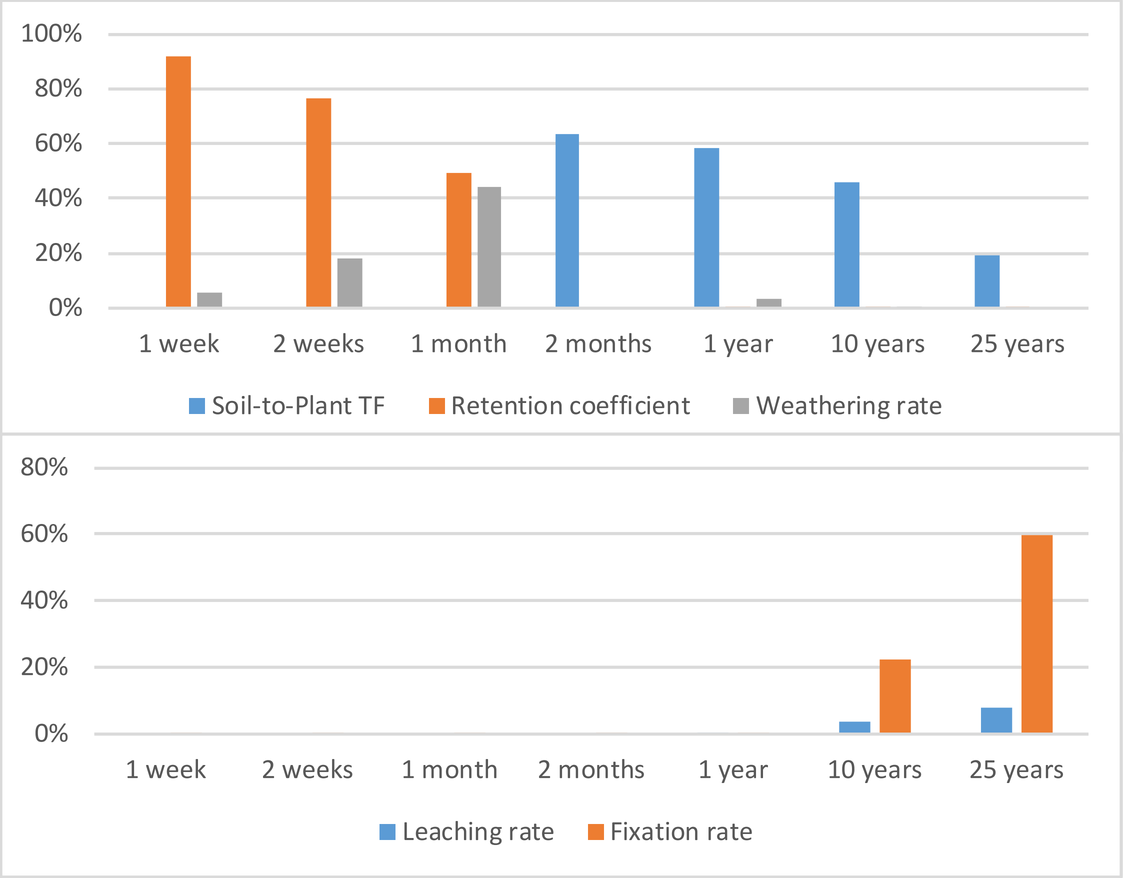
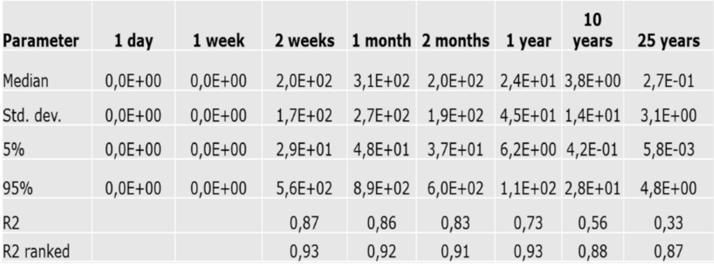


Figure 17. EASI as function of time – Cs-137 Leafy vegetables

Some caution is nonethless required to avoid over-interpretation. In particular we lack insight into the model sensitivity to those parameters which have been defined by look-up tables, as noted earlier in the text. In this particular case, we strongly suspect that LAI for leafy vegetables would have been defined as sensitive, at least in the initial phase post deposition, had there been a means of characterising variability in this parameter. Furthermore, the timing of events such as the start of the harvesting period and the time interval between the depositon event and the harvest are likely to confound any extrpolation of these findings to a generic situation. Although this can be partly accounted for by considering numerous scenarios/cases, the regional aspects of farming practices relevant for model parameterisation are still likely to exert a great, and currently largely unquantifiable, influence on the (conclusions that might be drawn from the) senstivity analyses.

Cs-137 Lamb

Results for the sensitivity analyses for ^{137}Cs in lamb meat are shown in Figures 18 and 19 for the wet deposition scenario defined above.



Parameter	1 day	1 week	2 weeks	1 month	2 months	1 year	10 years	25 years
Median	0,0E+00	0,0E+00	2,0E+02	3,1E+02	2,0E+02	2,4E+01	3,8E+00	2,7E-01
Std. dev.	0,0E+00	0,0E+00	1,7E+02	2,7E+02	1,9E+02	4,5E+01	1,4E+01	3,1E+00
5%	0,0E+00	0,0E+00	2,9E+01	4,8E+01	3,7E+01	6,2E+00	4,2E-01	5,8E-03
95%	0,0E+00	0,0E+00	5,6E+02	8,9E+02	6,0E+02	1,1E+02	2,8E+01	4,8E+00
R2			0,87	0,86	0,83	0,73	0,56	0,33
R2 ranked			0,93	0,92	0,91	0,93	0,88	0,87

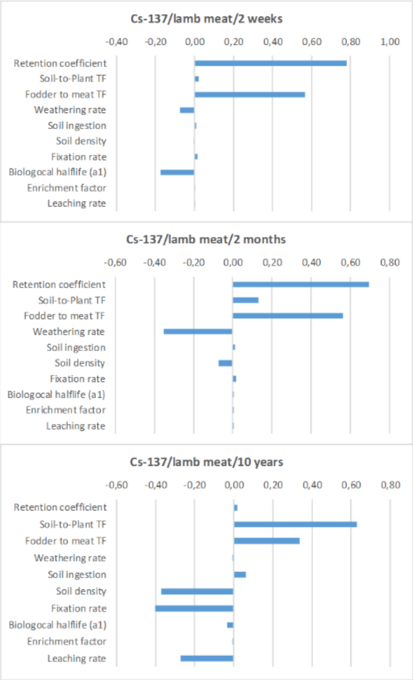


Figure 18. Cs-137 Lamb: (i) Probabilistic summary statistics and (ii) Spearman rank correlation coefficients between parameters and output, for various time points.

The sensitivity analysis for ^{137}Cs in lamb meat exhibit some similarities to those observed for leafy vegetables. The retention coefficient is a sensitive parameter in the initial weeks following the depositon event but for the consideration of lamb meat, in contrast to leafy vegetables, the weathering rate from vegetation is of lesser importance. The soil to plant transfer factor appears to be a highly sensitive parameter throughout a large fraction of the simulation period, from 1 to 25 years post deposition, although there is some decrease over time in relation to how much of the variance in the output is attributable to the variance in this input parameter. The feed to animal transfer coefficient (F_f in IAEA nomenclature) appears to constitute an important parameter throughout the simulation period although, in a similar way to that observed for F_v, the sensitivity of the output to this parameter has decreased quite substantially once 10 years or so have elapsed. In the final stages of the simulation, as was observed for ^{137}Cs in leafy vegetables, the variability associated with the parameters radionuclide fixation and leaching rate become important in accounting for the variance observed in ^{137}Cs activity concetrations in lamb meat. The data provided from the Spearman rank correlation coefficients indicate that there is an inverse relationship between these two, soil-related parameters and the model output. The consequence of this is that selection of greater migration and fixation rates leads to lower ^{137}Cs activity concentrations in lamb.

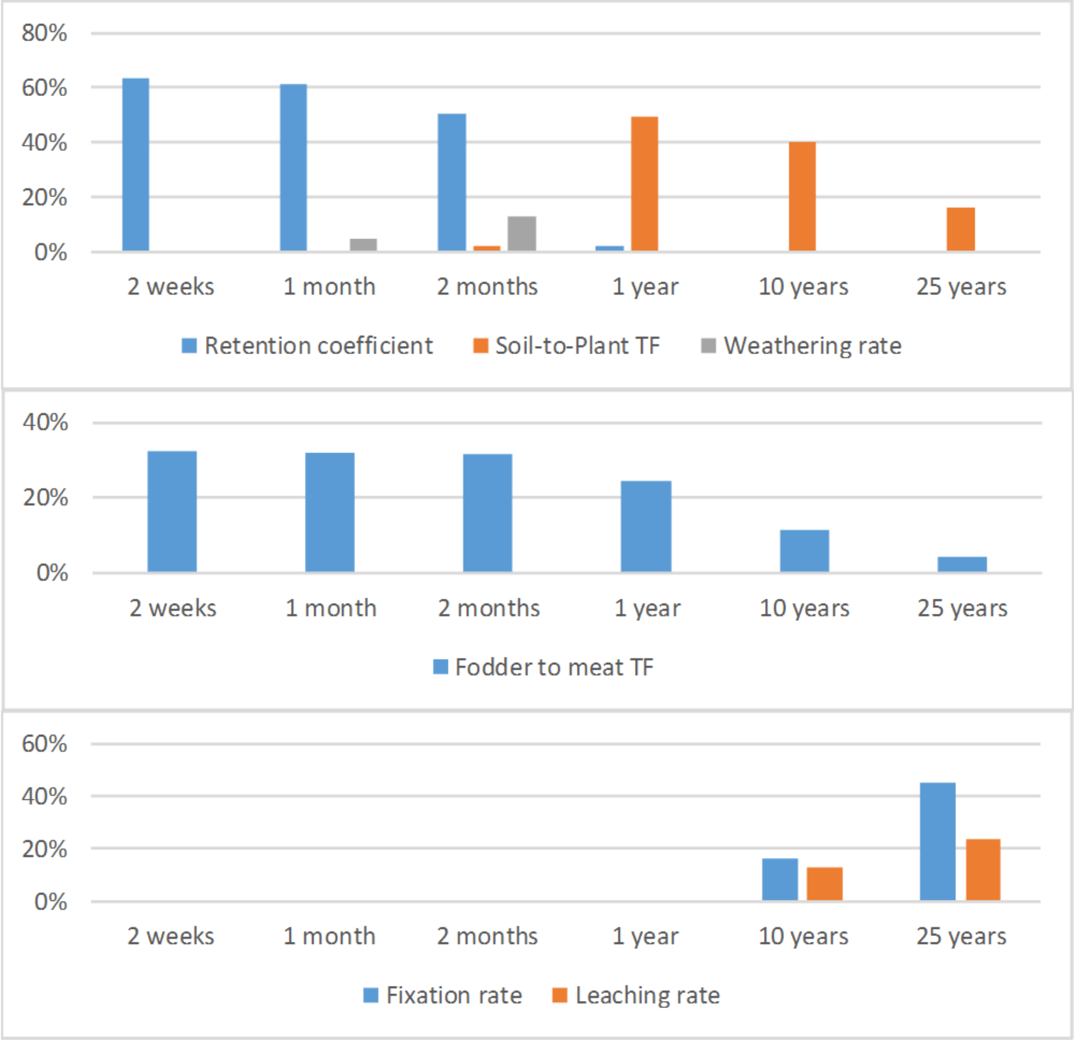


Figure 19. EASI as a function of time – Cs-137 Lamb

As before, over-interpretation should be avoided. Similar reservations to those outlined above for ^{137}Cs in leafy vegetables are relevant here, especially in relation to those parameters defined by look-up tables. In addition to the suspected importance of LAI and harvesting times (in this specific case with regards to grass cutting/hay harvesting periods) other parameters may also have been overlooked in this analysis. For example animal feeding regimes were not be included in this analyses although they are commonly accepted to constitute important, sensitive parameters (Thørring et al., 2016a).

The reader is referred to Appendix 7 for additional datasets for sensitivity analyses of ^{90}Sr and ^{131}I in leafy vegetables and lamb meat.

6 FDMT - conclusions and further deliberations

The ECOSYS-87/FDMT model has been successfully transferred to the ECOLEGO modelling platform and extensive tests have been made to ensure that the model is functioning correctly and providing the same outputs (for selected endpoints) compared to the original model versions. Data have been collated, primarily for element-dependent/radioecological parameters such as, soil to plant transfer factors and animal to feed transfer coefficients, to provide a 'current state-of the-art' update to the original ECOSYS-87/FDMT model. Unlike previous considerations of the ECOSYS-87/FDMT we have also collated underlying statistical information for parameters that enable uncertainty and sensitivity analysis. This new version of the ECOSYS-87/FDMT model on the ECOLEGO modelling platform has also been modified for regional conditions, examples specifically having been given for Norway and Spain, with focus on allowing changes in parameters. This has demonstrated the potential importance of accounting for specific agricultural practices (e.g. the slaughter of livestock at a given date, and factors such as growing season and harvest dates for selected crops). Probabilistic model runs for selected examples have been made to demonstrate the utility of characterising uncertainty in calculations. A proof of concept sensitivity analysis has also been performed using the uncertainty primarily driven by element-dependent/radioecological parameters and a restricted number of analytical methods. This means that the sensitivity analysis is not definitive because it provides us with only part of the picture. Currently we have not been able to provide insights into the importance, from the perspective of model sensitivity, of non-element-dependent/agricultural parameters for given deposition cases. The preliminary sensitivity analysis for selected cases (e.g. a given deposition of Cs-137 at a particular date) shows that the importance of different parameters changes with time for the selected endpoints (leafy vegetables and lamb meat) considered. Parameters such as retention coefficients and weathering rates being important in the initial phases following a deposition event and parameters dictating radionuclide soil processes becoming important at late stages – decades into the simulation. Soil to plant transfer for Cs-137 is an important parameter throughout most of the simulation period with the exception of early after deposition (up to 2 months).

6.1 Further consideration of the FDMT model in CONFIDENCE

Having implemented FDMT into the ECOLEGO platform gives us a flexible tool for application in the remainder of the CONFIDENCE work programme. For instance, if appropriate it will be possible to include processed based models of the behaviour of radionuclides in soil and subsequent plant uptake (e.g. Tarsitano et al. 2011) in the ECOLEGO implementation. Consideration will be given to this in our later deliverables.

The ECOLEGO FDMT implementation will be utilised to aid two further areas of our work programme as described below.

Iodine-131

Although the Chernobyl accident has provided knowledge on the behaviour of radiocaesium in European agricultural systems, there is still limited knowledge with regard to the behaviour and fate of other radionuclides following an atmospheric release. In the early phase of an emergency situation, ^{131}I is one of the most important radionuclides for which information on transfer is essential for assessing human food chain doses. There is also the potential for economic and societal consequences from the loss of crops that are vulnerable to contamination, particularly those with a short harvest to market window, such as soft fruits and new potatoes.

Because of the short-half life of ^{131}I, foliar uptake of radionuclides and translocation within plants are major factors influencing the concentrations of ^{131}I in foodstuffs. Our hypothesis was that the concentration of stable iodine in precipitation is assumed to influence the foliar uptake of I-131, and both translocation and soil-to-plant transfer should also be dependent on stable iodine concentration in plant and soils, respectively. To test this a series of field tracer experiments using ^{131}I tracer have been carried out at two sites in Norway: a coastal site in western Norway (Fureneset) with high sea salt and stable iodine deposition and an inland site in south-eastern Norway (Apelsvoll) with low salt and stable iodine deposition. In the first set of experiments, ^{131}I tracer (in artificial rainwater with and without sea salts mimicking rainwater for inland and coastal environments respectively) was sprayed on grass and barley at the two field sites three times during the growing season (June-August) and samples taken for three weeks after each spraying. In the second experiment, grass and potato plants were sprayed. With regards to the latter, the tracer was sprayed before new potatoes were ready to harvest to investigate the potential for translocation from leaves to tubers.

Although data are still being analysed, results show that ^{131}I concentration in grass and barley at both sites was dominated by interception and changes in biomass, with little wash off from plant to soil. There was also no discernible soil to grass transfer; and no impact of stable I on vegetation activity. However, preliminary mass balance results indicated a loss of total ^{131}I activity per m^2, particularly during the first 24 hours, suggesting that there was loss due to evaporation.

Results from barley spraying showed that ^{131}I concentration in seed heads was about 1/3 of that in the whole plant. While there was little change in the concentration in whole barley grain after spraying, there was an increase in the percentage found in barley grain, due to increase in grain weight. Later in the growing season, a slight transfer from outer shell to the grain could be seen five days after spraying. Preliminary results from the potato study showed a small but significant transfer from leaves to tubers in the three weeks after spraying.

Follow-up studies on grass and potatoes will be carried out in summer 2019, together with translocation studies on strawberries at the two sites. Once the data analysis is complete, results will be used to improve the FDMT model and subsequently conduct a sensitivity analyses for ^{131}I.

Studies of ^{131}I biokinetics in dairy cattle have also been conducted and we will evaluate the potential of the data obtained to improve biokinetic models of ^{131}I in dairy cattle and subsequently if such models offer any improvement over the predictions of the updated FDMT model.

Evaluating the need to incorporate 'hot particles' into food chain models

Since the Chernobyl accident there has been recognition of the potential importance of particulate deposition (commonly referred to as 'hot particles') (IAEA 2011; Beresford et al., 2016b). The potential impact of particulate deposition on radionuclide mobility and ecosystem transfer has been recognised (Salbu et al., 2018); particles can be retained in soils with a comparatively low (initial) radionuclide mobility. Particles can therefore add to uncertainty in transfer estimates with the presence of particles resulting in an apparent increase in radionuclide availability with time (Kashparov et al., 2004). Later in the CONFIDENCE project, a deliverable report from WP3 will consider the importance of radioactive particles in radioecological models. One component of this work will focus on the adaptation of the FDMT model to account for the presence of particles in deposited material to determine if predictions are likely to be significantly impacted by the presence of particles or not. Various parameters used in FDMT could be influenced by the presence of particles such as:

- Deposition velocities, which will change as a function of particle size (and physico-chemical form). There is also a link to canopy interception and retention of radionuclides including radioactive particles to different plant types (Kato et al., 2012).
- Loss from the vegetation canopy (weathering rates) which will presumably be affected by particle characteristics
- Radionuclide root uptake which is likely to be affected by the presence of particles
- Translocation from the leaves to the edible part of the plant
- Feed to animal transfer coefficients (radionuclide Bq/kg in animal per Bq/day ingested) which may be affected by the presence of particles.

In a similar way to the procedure undertaken in this report whereby updated statistical data have been collated for default parameters, information will be collated for parameters, selected from the list above, where the presence of particles is predominant. Our starting point will be to consider the root uptake parameters (soil-plant concentration ratios) for ^{90}Sr accounting for particle weathering rates, which strongly depend on soil pH and speciation (oxidized or non-oxidized UO_2 fuel particles or transformed to extra inert forms such as UZr_xO_y). An important part of the FDMT model for which we will consider the need for modification is the soil processes model (i.e. radionuclide fixation, desorption and migration). To include particle behaviour it will be necessary to consider how to include the weathering of particles (and hence mobilisation of radionuclides) over time (Figure 20).

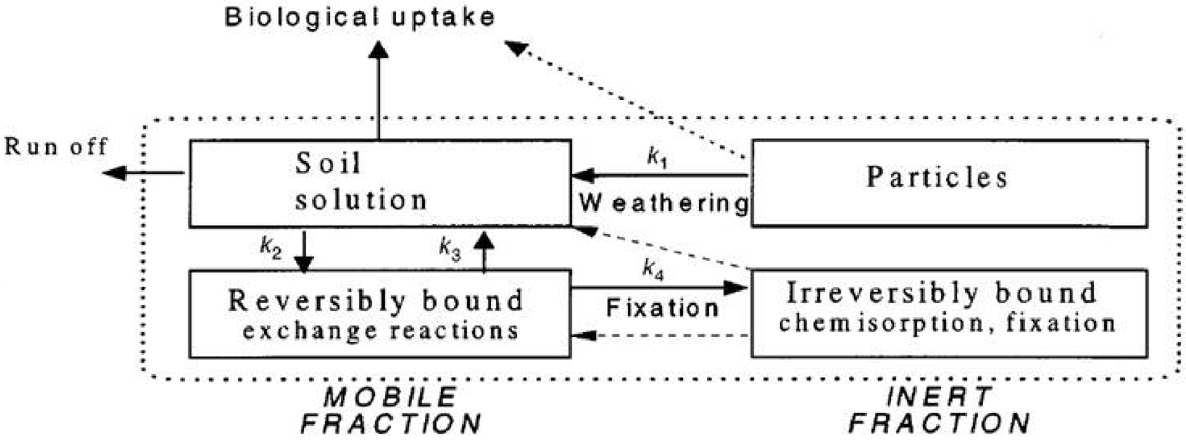


Figure 20. Distribution of radionuclide species in soil-water (sediment-water) systems (Salbu et al. 1998).

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Appendix 1: Compilation of responses to questionnaire on human food chain modelling following the Fukushima accident circulated to Japanese scientists

From personal contacts following the 2011 Fukushima Daiichi accident, we became aware that a number of Japanese scientists found that key radioecological material was lacking; including knowledge on some aspects of human food chain transfer. To try to gain more detailed information on what had been needed CONFIDENCE WP3 circulated a questionnaire (in Japanese and English) in summer 2017 to approximately one hundred Japanese scientists currently involved in radioecology and radiation protection. The aim of the questionnaire was to identify elements of human food chain transfer for which knowledge was lacking, or where more information would have made assessments and predictions easier. We received twenty-three responses to the questionnaire (a rate typical for such a survey https://surveyanyplace.com/average-survey-response-rate/). Responses are compiled (entered in purple text) in the questionnaire template on subsequent pages; the quotes are generally as submitted (some were summarised) with aspects relevant to CONFIDENCE highlighted in **bold text**. The results of the questionnaire are discussed in Section 2 of this deliverable.

Summary of Questionnaire responses

Questionnaire on human food-chain transfer in the early phase (the first few months) after the Fukushima accident

RESPONSES WILL BE TREATED ANONYMOUSLY（匿名回答）

Please put "X" in the box

1) Were you involved in radiation protection prior to the Fukushima accident?

東電福島第一原発事故以前から放射線防護に関わっていたでしょうか？

15 Yes   8 No.......... please go to Question 3

2) How long had you been involved in radiation protection at the time of the accident?

放射線防護に関わって何年くらいですか？

1 <1y   1 1-5 y   1 6-10 y   12 >10 y

3) Was the information/data you needed, to understand radionuclide transfer to foodstuffs or make predictions, readily available?

放射性核種の食品への移行や濃度の予測を行うにあたって必要な情報／データはすでに使用可能でしたか？

3 Yes   14 Sometimes (一部はあった)   6 No .... please go to Question 7

4) If your answer to Question 3 was yes/sometimes what were your main information sources? (you can choose more than one)

設問３の回答が yes や sometimes の場合、どれが情報源でしたか（複数回答可）

6	Internet	13	IAEA publications	12	Refereed publications
14	Text books/reports	13	Colleagues in Japan	2	Colleagues overseas
2	Models	5	Other (please specify): Newspapers, ICRP, EURANOS handbook, Japanese government’s website, Japanese-Tokyo- Fukushima governments		

5) If the information/data was available, was it useful?

その情報／データは役に立ちましたか？

16 Yes   1 No

(One person responded ‘Yes (sometimes)’ – the response was included in ‘Yes’)

6) If it was not useful - why was it not useful (e.g. advised parameters had no explanation, very large variation in recommended transfer parameters)? (please use as much space as you want to)

情報が役に立たなかった場合、どうして役に立たなかったのでしょうか？（例えば、パラメータの説明がない、推奨移行パラメータ値の幅が広い等）。いくつ回答いただいても結構ですが、英語でお答えください。

1. Radiocesium was deposited on the deciduous fruit tree which was prior to sprouting. More than the value of radiocesium which was predicted by the transfer factor from soil to fruit was detected in mature fruit. **Unfortunately, there was no information with regards to the migration of the radiocesium deposited on the canopy to fruit**.
2. There were **no specific transfer factor data for some specific plants and fishes**.
3. Because I am not an expert of environmental science, it was quite difficult to evaluate which model is suitable. It might be helpful if there are any “guidance” to evaluate how are they suitable for the situation.
4. I am studying about the live stock contamination. **The condition of calculation for transfer coefficient was different from Japanese environment** such as soils, plants and animals species.
5. The information was useful to me but people who were not familiar with parameter values could not understand, i.e., why parameters (TFs, food processing [washing vegetable]) varied largely. People asked "complete" removal from foods/drinks (during food production, e.g., growing crops, clean feeding, cooking etc.) although I explained them it was impossible. Outsiders but authorities (e.g. University Professors, Medical Doctors etc.) warned public too much at the time of accident; then people could not trust measurement results which were well predicted by the parameters/information available. **Lots of wrong information from scientists who were not familiar with radiation measurements under the emergency situation bothered us; they failed checking measurement methods & results as well as did not aware existence of global fallout.**
6. In general, the Japanese government took appropriate countermeasures for foodstuff production and marketing. It was **based on the existing knowledge from the Chernobyl accident.** The government started monitoring of foodstuff immediately after the accident. They knew the iodine-131 in milk, drinking water, meat and so on was the biggest risk for human health. They restricted planting rice based on the potential maximum transfer factor in the international database. Confusion in the Japanese society was what the criteria for concentration of radionuclide in foodstuffs are. At that time, 500 Bq/kg was the criteria for radiocesium for most foodstuffs at the emergency level, for example. However, many people couldn’t understand why the criteria depended on time, whether they were consistent with the international standard, whom they can trust, and so on. **Maybe there were too many information in the world, especially on the web; sometimes includes wrong information.** I think there was no new marvellous knowledge from the Fukushima accident. The Fukushima accident is just one case of nuclear accidents in the world. But the fact the foliar uptake was important in translocation is one of the examples that we newly obtained in Fukushima.
7. We **do not have transfer parameters obtained under non-equilibrium conditions**. So, it was difficult to estimate behaviour of radionuclides in the environment just after the accident.
8. The parameters are conditional data at some experimental conditions. Therefore, **detail information is needed to validate the parameters.**
9. Many data for transfer factor (TF) were available, but **experimental conditions were sometimes not clear**.
10. A large number of radioactivity measurements have been done shortly after the Fukushima accident by MEXT; however, these **measurements were not still enough for developing ingestion model** for each food item. In addition, significant uncertainty factors for estimating ingestion doses involve a wide variety of food ingested amount in individuals (including a potentially significant amount of ingestion by persons who could not recognize the food

consumption orders issued by the Japanese Government) and a dilution factor in market, as well as migration parameters in foodstuff. Model predictions for ingestion doses to the public of concern are suitable only for existing exposure situations, for the emergency situations, at least taking into account the Fukushima case. Such predications can be compared with human measurements (e.g. WBC). A low detection rate of WBCs for Fukushima residents have suggested that radioactivity in foodstuff in the market has been minimized due to strict food examinations. The model predictions may be useful for some residents who continue to foodstuff grown outdoors in contaminated areas; however, such persons rarely exist in the Fukushima case.

NOTE: Quotes have précised to highlight relevant text.

7) If information/data were not available – what was it that you required (include both radioecological and non-radioecological parameters as appropriate; please use as much space as you want to)

情報／データがなかった場合、どういう情報が必要だったのでしょうか？（放射生態学的でもそれ以外でも結構です）。いくつ回答いただいても結構ですが、英語でお答えください。

1. Useful countermeasures against the radiocesium contamination on the deciduous fruit tree in dormancy. Radiocesium migration mechanism via the above-ground parts of tree contaminated prior to sprouting.
2. Transfer parameters from the insect to animals.
3. Specific transfer factor data for some specific plants and fishes were necessary.
4. The information of the biological effects from low radiation and low radiation doses were necessary.
5. At least, data for ambient dose, quantity and component of contaminated radionucleoids are necessary. **Without reliable information, we cannot do anything**.
6. Important basic data for radiation dose assessment are inventory of radionuclides just after accident. It was **difficult to estimate radiation dose in using model**. And also **transfer parameters depending on seasons** are also important for dose estimation. Lack of information in the 2011 accident form my experiences is as follows: Translocation of radionuclides in fruit tree, Timing of intake of iodine tablet, Transfer of radionuclides in rice, Management of just before shipping animals, **Biological half time** determined by the experiment is very different from by field data, Public acceptance, Individual habit, management of agriculture.
7. I wanted bioavailability of fission products in domestic animals and any pharmacokinetic parameters a stable or a radioactive isotopes about these
8. The values regarding radio Cs activities itself and TFs for crops and foods is not directly interpreted as internal dose for human bodies. So, the public communication seemed to be little bit confusing at this point. So, it may be useful that **easy calculation tool for the conversion from food rCs activity to internal dose**.
9. **Treatment method for drinking water**, not from a laboratory tracer experiment (I mean simple ionic form is not enough), but data for real chemical forms of the radionuclide in drinking water. I still remember radioiodine removal from drinking water by boiling was first recommendation from the "real" authorities but it did not work at all; RO filtration was the best method. Through bark Cs uptake in early spring situation for trees. How long the "attached" Cs on the tree bark was taken up by trees was still in question. Tree bark removal cycle. **Soil to plant transfer data for wild edible plants**; translocation in tree for new shoots (edible). **Special food processing data** which were used for local residents. Fast uptake by biota in water (both marine and freshwater). Potential uptake of sediment by biota in water (**transfer from bottom sediment to biota**).
10. It was **difficult for us to obtain information** on the correct situation of the local site due to **confusion**, so the initial response to the accident was rather late. Daily efforts to

communicate with the relevant ministries and agencies are important to obtain the correct situation and to clear our role. In the Fukushima nuclear accident, past experience such as Chernobyl, Three Mile Island accident, and atmospheric nuclear weapons tests was very useful. However, there were some **lacking data peculiar to Japan**. For example, Japanese (Asian) people often eat bamboo shoots in spring season. A comparatively high concentration of radiocesium in bamboo shoots were found in the Kanto and Tohoku regions for several years after the Fukushima accident, and there is a continuing restriction on the distribution of bamboo shoots produced in some area. Little data on the radiocesium contamination in bamboo shoots were available at that time. Of course, **transfer factor and ecological half-life were not available, too**. Under such circumstances, delay in contamination control were occurred. **Information on foodstuffs peculiar to a nation is important**. **Decontamination factors of radiocesium by cooking and processing are also useful for the safety and security of the public because cooking and processing differ from country to country.**

11. The most required data was **whether can we convert the data of transfer factors from known species to Japanese species** (particularly, the Fukushima district specific species) and **how do we convert it**. This is not only in the meaning of food, but also a matter related to phytoremediation. In particular, the effectivity of the technique, phytoremediation, itself was not clear at the early phase, and thus, many human/monetary resources were put into that. Furthermore, it was a problem what conditions (e.g., **weather/climate, geology, and topography**) **affect the radionuclide uptake.**

12. **I wanted to know tap water was safety.** Many people bought plastic bottled water sampled at west area of Japan.

13. There were lots of data on the contamination levels in the agricultural and marine products, but much less on the level in actual meals that people eat every day. Because general public's concern existed on whether they can believe what their government and authority are saying, **we needed more data which are technically reliable** and measured by specialists of 'non-authorized' organizations (e.g. university researchers, non-profit organizations, journalists, only if technically sound of course). There were a bunch of caesium data available, but **not much prompt data for iodine** and, for a longer term, **strontium and other radionuclides**. **Contamination data before the beginning of regulation may be important for both understanding the early exposure level and evaluating the effectiveness of the regulation, but relevant data were very small in amount.**

14. Actually, **we needed meta-data but data themselves**. I believe information about the meta-data for radionuclide transfer at accident and emergency become common during public announcement and **training BEFORE accidents**. The Japanese Government had neglected them intentionally before (and after?) the Fukushima accident.

15. Critical conditions for accelerate transfer of radionuclides into crop.

16. Precise information on the history of ingestion by individuals during evacuation is important; however, such information is not well obtained in the Fukushima accident. **A precise model for predicting the radioactivity concentration time-trend for drinking water from each water source is also important**.

17. Captured and/or desorption ratio of a carbon cartridge or a charcoal filter for radioactive iodine consideration of methylation in the air to analyze air concentration of radioactive iodine. Distribution of radionuclide around a mouth of an animal such as cow to estimate a radiation dose to a tooth for analysis of EPR tooth dosimetry for confirming radiation dose to an animal including ingestion dose, although it is not directly related with human food-chain transfer…

18. After the Fukushima accident, I was engaged in the radioactivity measurement of ingestion foods (mainly agricultural foods). Our object of measurement was to clarify whether ingestion foods produced in Tokyo area exceeded the regulation value or not and our

> results were used for political decision of Tokyo Metropolitan Government. Therefore, we did not use transfer coefficient (transfer factor or concentration ratio), since the direct measurement result was more appropriate than the estimated value using transfer coefficient. Although we used effective dose coefficient compiled by ICRP to estimate internal dose, I thought this value might not be fit to 'Yes' to query 3.

NOTE: Quotes have précised to highlight relevant text.

Would you be happy to be contacted to expand on your responses if required?

お答えいただいた内容について今後問い合わせさせていただくことは可能でしょうか？

16 Yes … please provide your email address here:
6 No

One person did not respond

Thank you for taking the time to complete the questionnaire

ご協力ありがとうございました。

Please respond to Nick Beresford (nab@ceh.ac.uk) by 10th August

設問の和訳は一部意訳しております。ご了承ください（和訳協力：量研機構―放医研　田上恵子）

Appendix 2 – A comparison of FDMT default and IAEA (2010) radiological transfer parameter values

Table A2.1 Comparison of FDMT to IAEA plant-soil concentration ratio (F_v) values for crops.

Element	**FDMT crop**	**FDMT F_v**	**IAEA F_v AM**	**IAEA F_v ASD**	**IAEA F_v Min**	**IAEA F_v Max**	**IAEA F_v GM**	**IAEA F_v GSD**
Ag	Grass	1.0E-1						
Ag	Maize silage	1.0E-1						
Ag	Corn cobs	1.0E-1						
Ag	Potatoes	2.0E-2						
Ag	Beet	2.0E-2						
Ag	Beet leaves	2.0E-2	2.9E-5	4.2E-5	4.7E-6	1.0E-4	1.4E-5	2.6E-1
Ag	Cereals	1.0E-1						
Ag	Leafy vegetables	5.0E-2	3.6E-5	5.3E-5	5.9E-6	1.3E-4	1.8E-5	3.3E-1
Ag	Root vegetables	1.0E-2	2.2E-4	1.7E-4	8.0E-5	5.5E-4	1.8E-4	2.8E-1
Ag	Fruit vegetables	1.0E-2	6.2E-5	5.0E-5	1.8E-5	1.4E-4	4.5E-5	1.6E-1

Element	FDMT crop	FDMT F_v	IAEA F_v AM	IAEA F_v ASD	IAEA F_v Min	IAEA F_v Max	IAEA F_v GM	IAEA F_v GSD
Ag	Fruit	1.0E-2						
Ag	Berries	1.0E-2						
Am	Grass	2.0E-4	9.2E-4	2.2E-3	2.0E-5	9.6E-3	3.0E-4	8.2E-1
Am	Maize silage	2.0E-5	2.4E-4	5.3E-4	2.8E-6	3.0E-3	6.5E-5	1.4E+00
Am	Corn cobs	2.0E-5						
Am	Potatoes	1.0E-4	2.9E-4	9.7E-4	2.3E-6	7.1E-3	4.4E-5	1.3E+00
Am	Beet	1.0E-4	1.0E-4	7.4E-5	2.4E-5	2.0E-4	8.0E-5	2.9E-1
Am	Beet leaves	1.0E-4	3.7E-5	3.8E-5	3.2E-6	1.2E-4	2.2E-5	2.6E-1
Am	Cereals	2.0E-5	1.7E-3	6.2E-3	6.4E-7	3.0E-2	1.9E-5	9.6E+00
Am	Leafy vegetables	1.0E-4	4.6E-5	4.8E-5	4.0E-6	1.5E-4	2.7E-5	3.3E-1
Am	Root vegetables	1.0E-4	1.2E-4	8.7E-5	2.8E-5	2.4E-4	9.4E-5	3.4E-1
Am	Fruit vegetables	1.0E-4	5.5E-5	5.1E+03	1.6E-6	1.3E-4	2.5E-5	3.5E-1
Am	Fruit	1.0E-4	1.8E-4	2.7E-4	1.3E-6	6.2E-4	3.1E-5	2.4E+00
Am	Berries	1.0E-4	1.5E-4	1.2E-4	6.5E-5	2.3E-4	1.2E-4	8.9E-1
Ba	Grass	3.0E-2						
Ba	Maize silage	5.0E-2						
Ba	Corn cobs	5.0E-2						
Ba	Potatoes	4.0E-3	1.1E-3					
Ba	Beet	4.0E-3	6.0E-4					
Ba	Beet leaves	4.0E-3	4.0E-4					
Ba	Cereals	1.0E-2	8.7E-4					
Ba	Leafy vegetables	2.0E-2	5.0E-4					
Ba	Root vegetables	2.0E-3	7.0E-4					
Ba	Fruit vegetables	2.0E-3	3.5E-4					
Ba	Fruit	2.0E-3						

Element	FDMT crop	FDMT F_v	IAEA F_v AM	IAEA F_v ASD	IAEA F_v Min	IAEA F_v Max	IAEA F_v GM	IAEA F_v GSD
Ba	Berries	2.0E-3						
Ce	Grass	2.0E-3	1.7E-1	2.0E-1	4.0E-3	7.0E-1	7.4E-2	1.0E+00
Ce	Maize silage	3.0E-3						
Ce	Corn cobs	3.0E-3						
Ce	Potatoes	1.0E-3	8.4E-4					
Ce	Beet	1.0E-3	7.2E-4					
Ce	Beet leaves	1.0E-3	4.8E-4					
Ce	Cereals	3.0E-3	5.1E-3	5.2E-3	2.1E-4	1.7E-2	2.7E-3	3.2E+00
Ce	Leafy vegetables	1.0E-3	6.0E-4					
Ce	Root vegetables	4.0E-4	8.4E-4					
Ce	Fruit vegetables	4.0E-4						
Ce	Fruit	4.0E-4	5.3E-4	1.3E-4	4.4E-4	6.2E-4		
Ce	Berries	4.0E-4						
Cm	Grass	2.0E-4	2.8E-4	2.0E-4	2.0E-5	7.2E-4	2.0E-4	4.8E-1
Cm	Maize silage	2.0E-5	1.3E-4	2.0E-4	1.4E-6	1.1E-3	5.0E-5	1.3E+00
Cm	Corn cobs	2.0E-5						
Cm	Potatoes	1.0E-4	7.1E-5	8.8E-5	2.3E-6	4.4E-4	3.2E-5	7.8E-1
Cm	Beet	1.0E-4	1.6E-4	1.7E-4	2.4E-5	4.7E-4	1.0E-4	3.6E-1
Cm	Beet leaves	1.0E-4	2.2E-4	2.4E-4	1.6E-5	6.5E-4	1.1E-4	3.6E-1
Cm	Cereals	2.0E-5	3.6E-5	3.7E-5	1.2E-6	1.7E-4	2.0E-5	2.9E+00
Cm	Leafy vegetables	1.0E-4	2.8E-4	3.0E-4	2.0E-5	8.1E-4	1.4E-4	4.5E-1
Cm	Root vegetables	1.0E-4	1.8E-4	2.0E-4	2.8E-5	5.5E-4	1.2E-4	4.2E-1
Cm	Fruit vegetables	1.0E-4	4.5E-5	4.2E-5	2.5E-6	9.8E-5	2.2E-5	3.2E-1
Cm	Fruit	1.0E-4	5.3E-4	1.3E-4	4.4E-4	6.2E-4		
Cm	Berries	1.0E-4						

Element	FDMT crop	FDMT F_v	IAEA F_v AM	IAEA F_v ASD	IAEA F_v Min	IAEA F_v Max	IAEA F_v GM	IAEA F_v GSD
Co	Grass	1.0E-2	2.2E-2	3.4E-2	4.2E-4	1.7E-1	9.0E-3	7.4E-1
Co	Maize silage	1.0E-2	1.2E-2	9.3E-3	1.5E-3	5.0E-2	8.8E-3	5.5E-1
Co	Corn cobs	5.0E-3	3.7E-2	9.4E-2	7.7E-4	4.8E-1	8.5E-3	3.5E+00
Co	Potatoes	2.0E-2	2.3E-2	3.2E-2	2.1E-3	1.4E-1	1.1E-2	6.3E-1
Co	Beet	2.0E-2	1.8E-2	2.2E-2	5.6E-3	8.6E-2	1.3E-2	2.6E-1
Co	Beet leaves	7.0E-2	2.0E-2	1.8E-2	1.0E-3	8.0E-2	1.4E-2	2.2E-1
Co	Cereals	5.0E-3	3.2E-2	8.7E-2	3.5E-4	6.3E-1	7.4E-3	4.8E+00
Co	Leafy vegetables	3.0E-2	2.5E-2	2.2E-2	1.3E-3	1.0E-1	1.7E-2	2.7E-1
Co	Root vegetables	2.0E-2	2.1E-2	2.5E-2	6.6E-3	1.0E-1	1.5E-2	3.1E-1
Co	Fruit vegetables	5.0E-3	1.1E-2	4.2E-3	4.0E-3	1.6E-2	9.8E-3	1.1E-1
Co	Fruit	5.0E-3	4.8E-3					
Co	Berries	5.0E-3						
Cs	Grass	5.0E-2	1.1E-1	1.6E-1	2.0E-3	1.0E+00	5.0E-2	8.2E-1
Cs	Maize silage	2.0E-2	3.0E-2	2.8E-2	7.5E-4	1.2E-1	1.8E-2	7.5E-1
Cs	Corn cobs	1.0E-2	4.7E-2	4.8E-2	2.6E-3	2.2E-1	2.8E-2	2.6E+00
Cs	Potatoes	1.0E-2	2.1E-2	2.5E-2	8.4E-4	1.3E-1	1.2E-2	6.3E-1
Cs	Beet	5.0E-3	9.0E-3	1.3E-2	1.2E-4	1.1E-1	5.0E-3	3.6E-1
Cs	Beet leaves	3.0E-2	1.4E-2	1.7E-2	2.4E-5	7.8E-2	4.8E-3	4.8E-1
Cs	Cereals	2.0E-2	6.6E-2	1.3E-1	1.7E-4	7.8E-1	2.5E-2	3.6E+00
Cs	Leafy vegetables	2.0E-2	1.7E-2	2.1E-2	3.0E-5	9.8E-2	6.0E-3	6.0E-1
Cs	Root vegetables	1.0E-2	1.1E-2	1.5E-2	1.4E-4	1.2E-1	5.9E-3	4.2E-1
Cs	Fruit vegetables	1.0E-2	4.9E-3	1.1E-2	4.9E-5	5.1E-2	1.5E-3	2.9E-1
Cs	Fruit	2.0E-2	1.5E-2	2.2E-2	8.6E-4	8.0E-2	5.8E-3	1.5E+00
Cs	Berries	2.0E-2	2.6E-3	1.9E-3	6.9E-4	5.7E-3	2.1E-3	8.1E-1
I	Grass	1.0E-1	9.0E-3	2.8E-2	1.8E-4	1.0E-1	7.4E-4	1.2E+00

Element	FDMT crop	FDMT F_v	IAEA F_v AM	IAEA F_v ASD	IAEA F_v Min	IAEA F_v Max	IAEA F_v GM	IAEA F_v GSD
I	Maize silage	1.0E-1						
I	Corn cobs	1.0E-1						
I	Potatoes	1.0E-1	2.1E-2					
I	Beet	1.0E-1	1.6E-3	1.4E-3	1.7E-4	5.6E-3	9.2E-4	3.6E-1
I	Beet leaves	1.0E-1	1.3E-3	2.3E-3	8.8E-5	8.0E-3	5.2E-4	3.0E-1
I	Cereals	1.0E-1	1.2E-3	2.4E-3	8.7E-5	9.6E-3	5.5E-4	2.0E+00
I	Leafy vegetables	1.0E-1	1.6E-3	2.9E-3	1.1E-4	1.0E-2	6.5E-4	3.7E-1
I	Root vegetables	1.0E-1	1.8E-3	1.7E-3	2.0E-4	6.6E-3	1.1E-3	4.2E-1
I	Fruit vegetables	1.0E-1	7.0E-3					
I	Fruit	1.0E-1	1.2E-2	1.2E-2	4.1E-4	3.1E-2	6.3E-3	1.6E+00
I	Berries	1.0E-1						
La	Grass	1.0E-1	4.0E-3					
La	Maize silage	1.0E-1	2.2E-5	4.0E-6	1.9E-5	2.5E-5		
La	Corn cobs	1.0E-1						
La	Potatoes	1.0E-1	1.8E-4	2.7E-4	1.5E-5	8.4E-4	8.2E-5	7.8E-1
La	Beet	1.0E-1	2.9E-4	2.5E-4	5.4E-5	7.2E-4	1.9E-4	3.2E-1
La	Beet leaves	1.0E-1	6.6E-4	4.8E-4	8.8E-5	1.2E-3	4.6E-4	2.2E-1
La	Cereals	1.0E-1	1.7E-5					
La	Leafy vegetables	1.0E-1	8.2E-4	6.0E-4	1.1E-4	1.5E-3	5.7E-4	2.7E-1
La	Root vegetables	1.0E-1	3.4E-4	2.9E-4	6.3E-5	8.4E-4	2.2E-4	3.8E-1
La	Fruit vegetables	1.0E-1	4.2E-4	5.0E-6	4.1E-4	4.2E-4		
La	Fruit	1.0E-1						
La	Berries	1.0E-1						
Mn	Grass	8.0E-1	1.5E-1	9.6E-2	2.2E-2	5.4E-1	1.3E-1	3.8E-1
Mn	Maize silage	6.0E-2						

Element	FDMT crop	FDMT F_v	IAEA F_v AM	IAEA F_v ASD	IAEA F_v Min	IAEA F_v Max	IAEA F_v GM	IAEA F_v GSD
Mn	Corn cobs	6.0E-2	8.2E-2	6.5E-2	1.5E-2	2.6E-1	6.4E-2	1.8E+00
Mn	Potatoes	2.0E-2	1.4E-2	1.4E-2	2.5E-3	6.3E-2	9.9E-3	4.6E-1
Mn	Beet	2.0E-2	1.3E-1	1.7E-1	1.8E-3	4.7E-1	5.0E-2	6.6E-1
Mn	Beet leaves	2.0E-2	4.6E-2	4.2E-2	4.2E-3	2.4E-1	3.3E-2	1.9E-1
Mn	Cereals	2.0E-1	4.3E-1	4.6E-1	1.2E-1	2.3E+00	2.4E-1	2.9E+00
Mn	Leafy vegetables	8.0E-2	5.8E-2	5.3E-2	5.2E-3	3.0E-1	4.1E-2	2.4E-1
Mn	Root vegetables	2.0E-2	1.5E-1	2.0E-1	2.1E-3	5.5E-1	5.9E-2	7.7E-1
Mn	Fruit vegetables	3.0E-2	4.2E-2	5.4E-2	7.0E-3	1.1E-1	2.2E-2	2.9E-1
Mn	Fruit	3.0E-2	3.9E-3					
Mn	Berries	3.0E-2						
Mo	Grass	5.0E-2						
Mo	Maize silage	5.0E-2	1.8E-1					
Mo	Corn cobs	5.0E-2						
Mo	Potatoes	1.0E-2						
Mo	Beet	1.0E-2	3.8E-2		2.8E-3	5.0E-2		
Mo	Beet leaves	2.0E-2	4.1E-2		1.7E-2	6.4E-2		
Mo	Cereals	5.0E-2	7.0E-1					
Mo	Leafy vegetables	2.0E-2	5.1E-2		2.1E-2	8.0E-2		
Mo	Root vegetables	1.0E-2	4.5E-2		3.2E-3	5.9E-2		
Mo	Fruit vegetables	5.0E-3						
Mo	Fruit	5.0E-3						
Mo	Berries	5.0E-3						
Na	Grass	5.0E-2	2.0E-2					
Na	Maize silage	5.0E-2						
Na	Corn cobs	5.0E-2						

Element	FDMT crop	FDMT F_v	IAEA F_v AM	IAEA F_v ASD	IAEA F_v Min	IAEA F_v Max	IAEA F_v GM	IAEA F_v GSD
Na	Potatoes	5.0E-2	6.3E-3					
Na	Beet	5.0E-2	3.6E-3					
Na	Beet leaves	5.0E-2	2.4E-3					
Na	Cereals	5.0E-2	8.7E-3					
Na	Leafy vegetables	5.0E-2	3.0E-3					
Na	Root vegetables	5.0E-2	4.2E-3					
Na	Fruit vegetables	5.0E-2	2.1E-3					
Na	Fruit	5.0E-2	2.4E-2					
Na	Berries	5.0E-2						
Nb	Grass	4.0E-3	4.0E-3					
Nb	Maize silage	6.0E-3						
Nb	Corn cobs	6.0E-3						
Nb	Potatoes	1.0E-3	8.4E-4					
Nb	Beet	1.0E-3	2.0E-3		9.6E-4	3.0E-3		
Nb	Beet leaves	1.0E-3	1.4E-3		6.4E-4	2.0E-3		
Nb	Cereals	4.0E-3	1.2E-2		1.7E-3	2.2E-2		
Nb	Leafy vegetables	2.0E-3	1.7E-3		8.0E-4	2.5E-3		
Nb	Root vegetables	5.0E-4	2.4E-3		1.1E-3	3.5E-3		
Nb	Fruit vegetables	5.0E-4	5.6E-4					
Nb	Fruit	5.0E-4						
Nb	Berries	5.0E-4						
Nd	Grass	1.0E-1						
Nd	Maize silage	1.0E-1						
Nd	Corn cobs	1.0E-1						
Nd	Potatoes	1.0E-1						

Element	FDMT crop	FDMT F_v	IAEA F_v AM	IAEA F_v ASD	IAEA F_v Min	IAEA F_v Max	IAEA F_v GM	IAEA F_v GSD
Nd	Beet	1.0E-1						
Nd	Beet leaves	1.0E-1						
Nd	Cereals	1.0E-1						
Nd	Leafy vegetables	1.0E-1						
Nd	Root vegetables	1.0E-1						
Nd	Fruit vegetables	1.0E-1						
Nd	Fruit	1.0E-1						
Nd	Berries	1.0E-1						
Np	Grass	1.0E-2	2.0E-2	2.6E-2	2.6E-3	9.4E-2	1.2E-2	5.4E-1
Np	Maize silage	3.0E-3	8.5E-3	7.8E-3	3.5E-4	2.8E-2	4.8E-3	8.3E-1
Np	Corn cobs	3.0E-3	4.1E-3	5.6E-3	8.5E-5	8.0E-3		
Np	Potatoes	2.0E-3	1.7E-3	1.4E-3	1.5E-4	5.7E-3	1.2E-3	5.3E-1
Np	Beet	2.0E-3	3.1E-3	1.3E-3	6.0E-4	4.3E-3	2.6E-3	1.2E-1
Np	Beet leaves	3.0E-3	3.2E-3	2.6E-3	4.0E-4	6.4E-3	2.2E-3	2.4E-1
Np	Cereals	2.0E-3	6.5E-3	1.0E-2	2.0E-5	6.2E-2	2.5E-3	4.4E+00
Np	Leafy vegetables	2.0E-3	4.0E-3	3.3E-3	5.0E-4	8.0E-3	2.7E-3	3.0E-1
Np	Root vegetables	2.0E-3	3.6E-3	1.5E-3	7.0E-4	5.0E-3	3.1E-3	2.8E-1
Np	Fruit vegetables	3.0E-3	1.6E-3	1.1E-3	2.8E-4	4.0E-3	1.3E-3	1.7E-1
Np	Fruit	3.0E-3						
Np	Berries	3.0E-3						
Pr	Grass	1.0E-1						
Pr	Maize silage	1.0E-1						
Pr	Corn cobs	1.0E-1						
Pr	Potatoes	1.0E-1						
Pr	Beet	1.0E-1						

Element	FDMT crop	FDMT F_v	IAEA F_v AM	IAEA F_v ASD	IAEA F_v Min	IAEA F_v Max	IAEA F_v GM	IAEA F_v GSD
Pr	Beet leaves	1.0E-1						
Pr	Cereals	1.0E-1						
Pr	Leafy vegetables	1.0E-1						
Pr	Root vegetables	1.0E-1						
Pr	Fruit vegetables	1.0E-1						
Pr	Fruit	1.0E-1						
Pr	Berries	1.0E-1						
Pu	Grass	2.0E-4	1.9E-4	2.0E-4	1.3E-5	7.8E-4	1.1E-4	6.0E-1
Pu	Maize silage	2.0E-3	2.0E-5	2.0E-5	5.0E-7	8.0E-5	1.3E-5	6.8E-1
Pu	Corn cobs	2.0E-3	2.6E-6					
Pu	Potatoes	1.0E-4	8.0E-5	1.4E-4	8.0E-7	1.1E-3	2.3E-5	1.2E+00
Pu	Beet	1.0E-4	2.0E-4	3.0E-4	8.4E-6	7.0E-4	4.7E-5	1.2E+00
Pu	Beet leaves	2.0E-3	9.6E-6	7.4E-6	8.0E-7	2.3E-5	6.6E-6	2.2E-1
Pu	Cereals	1.0E-4	4.5E-5	1.1E-4	1.7E-7	9.6E-4	8.3E-6	5.8E+00
Pu	Leafy vegetables	1.0E-4	1.2E-5	9.3E-6	1.0E-6	2.9E-5	8.3E-6	2.7E-1
Pu	Root vegetables	1.0E-4	2.4E-4	3.5E-4	9.8E-6	8.1E-4	5.5E-5	1.4E+00
Pu	Fruit vegetables	1.0E-4	6.1E-6	3.8E-6	4.2E-7	1.4E-5	4.6E-6	1.9E-1
Pu	Fruit	1.0E-4	2.6E-3	6.6E-3	1.3E-6	2.1E-2	1.4E-4	2.9E+00
Pu	Berries	1.0E-4	1.7E-4	1.5E-4	6.4E-5	2.7E-4	1.3E-4	1.0E+00
Rb	Grass	1.0E-1						
Rb	Maize silage	1.0E-1						
Rb	Corn cobs	1.0E-1						
Rb	Potatoes	1.0E-1						
Rb	Beet	1.0E-1	1.1E-1					
Rb	Beet leaves	1.0E-1	5.0E-2		2.7E-2	7.2E-2		

Element	FDMT crop	FDMT F_v	IAEA F_v AM	IAEA F_v ASD	IAEA F_v Min	IAEA F_v Max	IAEA F_v GM	IAEA F_v GSD
Rb	Cereals	1.0E-1	7.8E-1					
Rb	Leafy vegetables	1.0E-1	6.2E-2		3.4E-2	9.0E-2		
Rb	Root vegetables	1.0E-1	1.3E-1					
Rb	Fruit vegetables	1.0E-1						
Rb	Fruit	1.0E-1						
Rb	Berries	1.0E-1						
Rh	Grass	1.0E-1						
Rh	Maize silage	1.0E-1						
Rh	Corn cobs	1.0E-1						
Rh	Potatoes	1.0E-1						
Rh	Beet	1.0E-1						
Rh	Beet leaves	1.0E-1						
Rh	Cereals	1.0E-1						
Rh	Leafy vegetables	1.0E-1						
Rh	Root vegetables	1.0E-1						
Rh	Fruit vegetables	1.0E-1						
Rh	Fruit	1.0E-1						
Rh	Berries	1.0E-1						
Ru	Grass	2.0E-2						
Ru	Maize silage	1.0E-2						
Ru	Corn cobs	1.0E-2						
Ru	Potatoes	1.0E-2	1.1E-3					
Ru	Beet	1.0E-2	1.2E-3					
Ru	Beet leaves	1.0E-2	1.1E-2	8.8E-3	1.6E-3	1.8E-2	7.2E-3	3.0E-1
Ru	Cereals	1.0E-2	3.7E-3	2.6E-3	5.2E-4	8.7E-3	2.6E-3	2.3E+00

Element	FDMT crop	FDMT F_v	IAEA F_v AM	IAEA F_v ASD	IAEA F_v Min	IAEA F_v Max	IAEA F_v GM	IAEA F_v GSD
Ru	Leafy vegetables	1.0E-2	1.4E-2	1.1E-2	2.0E-3	2.3E-2	9.0E-3	3.7E-1
Ru	Root vegetables	1.0E-2	1.4E-3					
Ru	Fruit vegetables	1.0E-2	1.4E-3					
Ru	Fruit	1.0E-2	1.3E-3	3.3E-4	1.1E-3	1.6E-3		
Ru	Berries	1.0E-2						
Sb	Grass	1.0E-1						
Sb	Maize silage	1.0E-1						
Sb	Corn cobs	2.0E-2						
Sb	Potatoes	2.0E-2	4.2E-4					
Sb	Beet	2.0E-2	7.9E-5	3.2E-5	4.8E-5	1.3E-4	7.4E-5	1.8E-1
Sb	Beet leaves	1.0E-1	1.0E-5	7.0E-6	1.8E-6	1.8E-5	7.5E-6	2.1E-1
Sb	Cereals	2.0E-2	2.4E-3	2.3E-3	2.6E-4	7.8E-3	1.6E-3	2.3E+00
Sb	Leafy vegetables	1.0E-1	1.3E-5	8.7E-6	2.2E-6	2.3E-5	9.4E-6	2.6E-1
Sb	Root vegetables	2.0E-2	9.2E-5	3.8E-5	5.6E-5	1.5E-4	8.7E-5	2.1E-1
Sb	Fruit vegetables	2.0E-2	2.9E-5	4.7E-5	1.1E-6	1.1E-4	9.1E-6	4.7E-1
Sb	Fruit	2.0E-2						
Sb	Berries	2.0E-2						
Sr	Grass	5.0E-1	3.4E-1	2.4E-1	1.1E-2	1.5E+00	2.6E-1	4.4E-1
Sr	Maize silage	3.0E-1	2.5E-1	1.9E-1	3.0E-2	7.5E-1	1.8E-1	1.5E+00
Sr	Corn cobs	2.0E-1	5.0E-1	5.2E-1	1.7E-3	2.2E+00	2.7E-1	3.5E+00
Sr	Potatoes	5.0E-2	5.0E-2	4.6E-2	1.6E-3	3.4E-1	3.4E-2	6.3E-1
Sr	Beet	4.0E-1	1.8E-1	1.7E-1	3.6E-3	5.8E-1	8.6E-2	4.9E-1
Sr	Beet leaves	8.0E-1	1.5E-1	1.4E-1	3.1E-4	6.2E-1	6.1E-2	4.8E-1
Sr	Cereals	2.0E-1	1.6E-1	1.7E-1	3.1E-3	8.7E-1	9.6E-2	2.3E+00
Sr	Leafy vegetables	4.0E-1	1.9E-1	1.8E-1	3.9E-4	7.8E-1	7.6E-2	6.0E-1

Element	FDMT crop	FDMT F_v	IAEA F_v AM	IAEA F_v ASD	IAEA F_v Min	IAEA F_v Max	IAEA F_v GM	IAEA F_v GSD
Sr	Root vegetables	3.0E-1	2.1E-1	2.0E-1	4.2E-3	6.7E-1	1.0E-1	5.7E-1
Sr	Fruit vegetables	2.0E-1	6.9E-2	1.3E-1	5.0E-4	5.5E-1	2.5E-2	3.9E-1
Sr	Fruit	1.0E-1	2.5E-2	1.9E-2	1.2E-3	7.0E-2	1.7E-2	9.7E-1
Sr	Berries	1.0E-1	5.5E-2	3.7E-2	1.4E-2	1.1E-1	4.4E-2	7.6E-1
Tc	Grass	1.0E+00						
Tc	Maize silage	1.0E+00						
Tc	Corn cobs	1.0E+00						
Tc	Potatoes	1.0E+00						
Tc	Beet	1.0E+00						
Tc	Beet leaves	1.0E+00						
Tc	Cereals	1.0E+00						
Tc	Leafy vegetables	1.0E+00						
Tc	Root vegetables	1.0E+00						
Tc	Fruit vegetables	1.0E+00						
Tc	Fruit	1.0E+00						
Tc	Berries	1.0E+00						
Te	Grass	5.0E-3	2.0E-1					
Te	Maize silage	1.0E-2						
Te	Corn cobs	1.0E-2						
Te	Potatoes	1.0E-3	4.2E-2					
Te	Beet	1.0E-3	3.6E-2					
Te	Beet leaves	1.0E-3	2.4E-2					
Te	Cereals	3.0E-3	8.7E-2					
Te	Leafy vegetables	3.0E-3	3.0E-2					
Te	Root vegetables	4.0E-4	4.2E-2					

Element	**FDMT crop**	**FDMT F_v**	**IAEA F_v AM**	**IAEA F_v ASD**	**IAEA F_v Min**	**IAEA F_v Max**	**IAEA F_v GM**	**IAEA F_v GSD**
Te	Fruit vegetables	4.0E-4	2.1E-2					
Te	Fruit	4.0E-4						
Te	Berries	4.0E-4						
Y	Grass	1.0E-2	1.0E-3					
Y	Maize silage	1.0E-2						
Y	Corn cobs	1.0E-2						
Y	Potatoes	1.0E-2	2.1E-4					
Y	Beet	1.0E-2	2.4E-4					
Y	Beet leaves	1.0E-2	1.6E-4					
Y	Cereals	1.0E-2	4.4E-4					
Y	Leafy vegetables	1.0E-2	2.0E-4					
Y	Root vegetables	1.0E-2	2.8E-4					
Y	Fruit vegetables	1.0E-2	1.4E-4					
Y	Fruit	1.0E-2						
Y	Berries	1.0E-2						
Zr	Grass	4.0E-4	2.0E-3					
Zr	Maize silage	6.0E-4						
Zr	Corn cobs	6.0E-4						
Zr	Potatoes	1.0E-4	4.2E-4					
Zr	Beet	1.0E-4	4.8E-4					
Zr	Beet leaves	1.0E-4	3.2E-4					
Zr	Cereals	4.0E-4	8.7E-4					
Zr	Leafy vegetables	2.0E-4	4.0E-4					
Zr	Root vegetables	5.0E-5	5.6E-4					
Zr	Fruit vegetables	5.0E-5	2.8E-4					

Element	FDMT crop	FDMT F_v	IAEA F_v AM	IAEA F_v ASD	IAEA F_v Min	IAEA F_v Max	IAEA F_v GM	IAEA F_v GSD
Zr	Fruit	5.0E-5						
Zr	Berries	5.0E-5						

Beet: IAEA TF for Root Crops (Roots), DM for Swede see Table 82 in IAEA (2009,2010); **Beet leaves:** IAEA TF for Leafy vegetables (Leaves), DM for Spinach see Table 82 in IAEA (2009,2010); **Berries:** IAEA TF for Shrubs (Fruits), DM for Strawberry see Table 83 in IAEA (2009,2010); **Cereals:** IAEA TF for Cereals (Grain), DM estimated from cereal grains see Table 82 in IAEA (2009,2010); **Corn cobs:** IAEA TF for Maize (Grain), DM for Maize grain see Table 82 in IAEA (2009,2010); **Fruit:** IAEA TF for Woody Trees (Fruits) with the exception of that Mn which was for Fruits, DM estimated from non-berry fruits see Table 83 in IAEA (2009,2010); **Fruit vegetables:** IAEA TF for Non-Leafy Vegetables (Fruits) with the exception of those TF's for Am, Ba, Co, Cs, I Na, Np, Pu which were for Non-Leafy Vegetables (fruits, berries), DM estimated from relevant crop types see Table 82 in IAEA (2009,2010); **Grass:** IAEA TF for Pasture (Stems and Shoots), DM for Pasture see Table 84 in IAEA (2009,2010); **Leafy vegetables:** IAEA TF for Leafy vegetables (Leaves), DM estimated from leafy vegetable types see Table 82 in IAEA (2009,2010); **Maize silage:** IAEA TF for Maize (Stems and Shoots), DM for Corn silage see Table 84 in IAEA (2009,2010); **Potatoes**: IAEA TF for Tubers, DM for Potato see Table 82 in IAEA (2009,2010); **Root vegetables:** IAEA TF for Root Crops (Roots), DM estimated from root vegetables types see Table 82 in IAEA (2009,2010) . Blank cells signify no data in IAEA (2009,2010) .

Table A2.2 Comparison of FDMT to IAEA transfer coefficient values (d kg^{-1}, d l^{-1}) for milk (F_m) and meat (F_f). 'IAEA' values for lamb in red italics have been estimated for this deliverable (see Section 3.2); IAEA (2010) values for lamb in black are reportedly for adults.

Element	**FDMT Animal product**	**FDMT F_f or F_m**	**IAEA F_f or F_m AM**	**IAEA F_f or F_m ASD**	**IAEA F_f or F_m Min**	**IAEA F_f or F_m Max**	**IAEA F_f or F_m GM**	**IAEA F_f or F_m GSD**
Ag	Cow milk	2.0E-4						
Ag	Sheep milk	2.5E-3						
Ag	Goat milk	2.5E-3						
Ag	Beef (cow)	1.0E-3						
Ag	Beef (bull)	1.0E-3						
Ag	Veal	3.0E-3						
Ag	Pork	5.0E-3						
Ag	Lamb	1.0E-2	4.8E-4					
Ag	*Lamb*	*1.0E-2*	*4.8E-4*					
Ag	Chicken	5.0E-1						
Ag	Eggs	5.0E-1						
Am	Cow milk	1.0E-6	4.2E-7					
Am	Sheep milk	1.0E-5						
Am	Goat milk	1.0E-5	6.9E-6		3.7E-6	1.0E-5		
Am	Beef (cow)	3.0E-4	5.0E-4					
Am	Beef (bull)	3.0E-4	5.0E-4					
Am	Veal	1.0E-3	5.0E-4					
Am	Pork	1.0E-3						
Am	Lamb	3.0E-3	1.1E-4					
Am	Chicken	2.0E-4						
Am	Eggs	5.0E-3	3.0E-3					
Ba	Cow milk	5.0E-4	2.5E-4	2.4E-4	3.8E-5	7.3E-4	1.6E-4	2.7E+00
Ba	Sheep milk	5.0E-3	4.1E-2					

Element	**FDMT Animal product**	**FDMT $F_f$or F_m**	**IAEA $F_f$or F_m AM**	**IAEA $F_f$or F_m ASD**	**IAEA $F_f$or F_m Min**	**IAEA $F_f$or F_m Max**	**IAEA $F_f$or F_m GM**	**IAEA $F_f$or F_m GSD**
Ba	Goat milk	5.0E-3	5.4E-2	8.7E-2	2.1E-3	1.5E-1	1.1E-2	9.9E+00
Ba	Beef (cow)	2.0E-4	1.4E-4		5.0E-5	2.3E-4		
Ba	Beef (bull)	2.0E-4	1.4E-4		5.0E-5	2.3E-4		
Ba	Veal	6.0E-4	1.4E-4		5.0E-5	2.3E-4		
Ba	Pork	1.0E-3						
Ba	Lamb	2.0E-3						
Ba	Chicken	1.0E-2	1.9E-2		9.2E-3	2.9E-2		
Ba	Eggs	9.0E-1	8.7E-1					
Ce	Cow milk	2.0E-5	4.7E-5	4.9E-5	2.0E-6	1.3E-4	2.0E-5	5.8E+00
Ce	Sheep milk	2.0E-4						
Ce	Goat milk	2.0E-4	4.0E-5					
Ce	Beef (cow)	8.0E-4						
Ce	Beef (bull)	8.0E-4						
Ce	Veal	2.0E-3						
Ce	Pork	4.0E-3						
Ce	Lamb	8.0E-3	2.5E-4					
Ce	*Lamb*	*8.0E-3*	*2.5E-4*					
Ce	Chicken	1.0E-2						
Ce	Eggs	5.0E-3	3.1E-3					
Cm	Cow milk	1.0E-6						
Cm	Sheep milk	1.0E-5						
Cm	Goat milk	1.0E-5						
Cm	Beef (cow)	1.0E-4						
Cm	Beef (bull)	1.0E-4						
Cm	Veal	3.0E-4						

Element	**FDMT Animal product**	**FDMT F_f or F_m**	**IAEA F_f or F_m AM**	**IAEA F_f or F_m ASD**	**IAEA F_f or F_m Min**	**IAEA F_f or F_m Max**	**IAEA F_f or F_m GM**	**IAEA F_f or F_m GSD**
Cm	Pork	3.0E-4						
Cm	Lamb	1.0E-3						
Cm	Chicken	2.0E-4						
Cm	Eggs	5.0E-3						
Co	Cow milk	2.0E-4	1.3E-4	1.1E-4	6.0E-5	3.0E-4	1.1E-4	2.0E+00
Co	Sheep milk	2.0E-3	2.7E-3		1.2E-3	4.1E-3		
Co	Goat milk	2.0E-3	5.0E-3					
Co	Beef (cow)	2.0E-4	5.2E-4	3.0E-4	1.3E-4	8.4E-4	4.3E-4	2.3E+00
Co	Beef (bull)	2.0E-4	5.2E-4	3.0E-4	1.3E-4	8.4E-4	4.3E-4	2.3E+00
Co	Veal	6.0E-4	5.2E-4	3.0E-4	1.3E-4	8.4E-4	4.3E-4	2.3E+00
Co	Pork	1.0E-3						
Co	Lamb	2.0E-3	1.2E-2		8.0E-3	1.6E-2		
Co	*Lamb*	*2.0E-3*	*1.2E-2*		*8.0E-3*	*1.6E-2*		
Co	Chicken	2.0E+00	9.7E-1		3.0E-2	1.9E+00		
Co	Eggs	3.0E-1	3.3E-2		2.6E-2	4.0E-2		
Cs	Cow milk	3.0E-3	6.1E-3	6.3E-3	6.0E-4	6.8E-2	4.6E-3	2.0E+00
Cs	Sheep milk	6.0E-2	7.7E-2	6.1E-2	6.0E-3	3.2E-1	5.8E-2	2.3E+00
Cs	Goat milk	6.0E-2	1.3E-1	8.0E-2	7.0E-3	3.3E-1	1.1E-1	2.2E+00
Cs	Beef (cow)	1.0E-2	3.0E-2	2.3E-2	4.7E-3	9.6E-2	2.2E-2	2.4E+00
Cs	Beef (bull)	4.0E-2	3.0E-2	2.3E-2	4.7E-3	9.6E-2	2.2E-2	2.4E+00
Cs	Veal	3.5E-1	3.0E-2	2.3E-2	4.7E-3	9.6E-2	2.2E-2	2.4E+00
Cs	Pork	4.0E-1	2.2E-1	9.0E-2	1.2E-1	4.0E-1	2.0E-1	1.5E+00
Cs	Lamb	5.0E-1	2.7E-1	2.6E-1	5.3E-2	1.3E+00	1.9E-1	2.2E+00
Cs	*Lamb*	*5.0E-1*	*8.7E-1*	*3.9E-1*	*3.6E-1*	*1.6E+00*	*8.0E-1*	*1.6E+00*
Cs	Chicken	4.5E+00	3.0E+00	1.3E+00	1.2E+00	5.6E+00	2.7E+00	1.6E+00

Element	FDMT Animal product	FDMT F_f or F_m	IAEA F_f or F_m AM	IAEA F_f or F_m ASD	IAEA F_f or F_m Min	IAEA F_f or F_m Max	IAEA F_f or F_m GM	IAEA F_f or F_m GSD
Cs	Eggs	3.0E-1	4.3E-1	1.6E-1	1.6E-1	7.1E-1	4.0E-1	1.5E+00
I	Cow milk	3.0E-3	9.1E-3	7.0E-3	4.0E-4	2.5E-2	5.4E-3	2.4E+00
I	Sheep milk	5.0E-1	3.5E-1	3.0E-1	3.0E-2	9.4E-1	2.3E-1	3.3E+00
I	Goat milk	5.0E-1	3.3E-1	2.3E-1	2.7E-2	7.7E-1	2.2E-1	2.9E+00
I	Beef (cow)	1.0E-3	1.2E-2	1.5E-2	2.0E-3	3.8E-2	6.7E-3	3.2E+00
I	Beef (bull)	1.0E-3	1.2E-2	1.5E-2	2.0E-3	3.8E-2	6.7E-3	3.2E+00
I	Veal	3.0E-3	1.2E-2	1.5E-2	2.0E-3	3.8E-2	6.7E-3	3.2E+00
I	Pork	3.0E-3	4.1E-2		1.5E-2	6.6E-2		
I	Lamb	1.0E-2	3.0E-2					
I	Chicken	1.0E-1	1.0E-2	5.6E-3	4.0E-3	1.5E-2	8.7E-3	2.0E+00
I	Eggs	2.8E+00	2.4E+00	5.7E-1	1.9E+00	3.2E+00	2.4E+00	1.3E+00
La	Cow milk	2.0E-5						
La	Sheep milk	2.0E-4						
La	Goat milk	2.0E-4						
La	Beef (cow)	3.0E-4	1.3E-4	2.0E-5	1.1E-4	1.5E-4	1.3E-4	1.2E+00
La	Beef (bull)	3.0E-4	1.3E-4	2.0E-5	1.1E-4	1.5E-4	1.3E-4	1.2E+00
La	Veal	1.0E-4	1.3E-4	2.0E-5	1.1E-4	1.5E-4	1.3E-4	1.2E+00
La	Pork	2.0E-3						
La	Lamb	3.0E-3						
La	Chicken	3.0E-3						
La	Eggs	3.0E-3						
Mn	Cow milk	1.0E-4	1.0E-4	1.5E-4	7.0E-6	3.3E-4	4.1E-5	4.9E+00
Mn	Sheep milk	1.0E-3	2.4E-3					
Mn	Goat milk	1.0E-3	1.0E-3					
Mn	Beef (cow)	5.0E-4	6.0E-4		6.0E-4	6.0E-4		

Element	**FDMT Animal product**	**FDMT $F_f$or F_m**	**IAEA $F_f$or F_m AM**	**IAEA $F_f$or F_m ASD**	**IAEA $F_f$or F_m Min**	**IAEA $F_f$or F_m Max**	**IAEA $F_f$or F_m GM**	**IAEA $F_f$or F_m GSD**
Mn	Beef (bull)	5.0E-4	6.0E-4		6.0E-4	6.0E-4		
Mn	Veal	2.0E-3	6.0E-4		6.0E-4	6.0E-4		
Mn	Pork	4.0E-3	5.3E-3					
Mn	Lamb	5.0E-3	9.0E-3					
Mn	*Lamb*	*5.0E-3*	*4.0E-4*	*8.4E-4*	*3.3E-5*	*2.5E-3*	*1.3E-4*	*3.9E+00*
Mn	Chicken	5.0E-2	1.9E-3		1.0E-3	2.8E-3		
Mn	Eggs	7.0E-2	4.4E-2	1.6E-2	3.2E-2	6.2E-2	4.2E-2	1.4E+00
Mo	Cow milk	1.0E-3	1.5E-3	1.7E-3	4.3E-4	5.2E-3	1.1E-3	2.3E+00
Mo	Sheep milk	1.0E-2						
Mo	Goat milk	1.0E-2	8.5E-3	2.5E-3	5.0E-3	1.1E-2	8.2E-3	1.4E+00
Mo	Beef (cow)	1.0E-3	1.0E-3					
Mo	Beef (bull)	1.0E-3	1.0E-3					
Mo	Veal	3.0E-3	1.0E-3					
Mo	Pork	3.0E-3						
Mo	Lamb	1.0E-2						
Mo	*Lamb*	*1.0E-2*	*6.7E-3*	*8.1E-3*	*2.2E-3*	*2.5E-2*	*4.7E-3*	*2.2E+00*
Mo	Chicken	1.0E+00	1.8E-1					
Mo	Eggs	1.0E+00	6.4E-1	1.9E-1	5.2E-1	8.7E-1	6.4E-1	1.3E+00
Na	Cow milk	2.0E-2	1.6E-2	1.5E-2	5.0E-3	5.0E-2	1.3E-2	2.0E+00
Na	Sheep milk	2.0E-1	1.0E-1					
Na	Goat milk	2.0E-1	1.2E-1					
Na	Beef (cow)	1.0E-2	1.5E-2		1.0E-2	2.0E-2		
Na	Beef (bull)	1.0E-2	1.5E-2		1.0E-2	2.0E-2		
Na	Veal	3.0E-2	1.5E-2		1.0E-2	2.0E-2		
Na	Pork	5.0E-2						

Element	FDMT Animal product	FDMT F_f or F_m	IAEA F_f or F_m AM	IAEA F_f or F_m ASD	IAEA F_f or F_m Min	IAEA F_f or F_m Max	IAEA F_f or F_m GM	IAEA F_f or F_m GSD
Na	Lamb	1.0E-1	1.1E-1					
Na	*Lamb*	*1.0E-1*	*1.5E+00*		*1.4E+00*	*1.7E+00*		
Na	Chicken	1.0E+00	7.0E+00					
Na	Eggs	6.0E+00	4.0E+00		1.9E+00	6.0E+00		
Nb	Cow milk	4.0E-7	4.1E-7					
Nb	Sheep milk	6.0E-6						
Nb	Goat milk	6.0E-6	6.4E-6					
Nb	Beef (cow)	3.0E-7	2.6E-7					
Nb	Beef (bull)	3.0E-7	2.6E-7					
Nb	Veal	1.0E-6	2.6E-7					
Nb	Pork	2.0E-6						
Nb	Lamb	3.0E-6						
Nb	Chicken	3.0E-4	3.0E-4					
Nb	Eggs	1.0E-3	1.0E-3					
Nd	Cow milk	2.0E-5						
Nd	Sheep milk	2.0E-4						
Nd	Goat milk	2.0E-4						
Nd	Beef (cow)	3.0E-4						
Nd	Beef (bull)	3.0E-4						
Nd	Veal	1.0E-4						
Nd	Pork	2.0E-3						
Nd	Lamb	3.0E-3						
Nd	Chicken	3.0E-2						
Nd	Eggs	7.0E-3						
Np	Cow milk	5.0E-6						

Element	FDMT Animal product	FDMT $F_f$or F_m	IAEA $F_f$or F_m AM	IAEA $F_f$or F_m ASD	IAEA $F_f$or F_m Min	IAEA $F_f$or F_m Max	IAEA $F_f$or F_m GM	IAEA $F_f$or F_m GSD
Np	Sheep milk	5.0E-5						
Np	Goat milk	5.0E-5	5.3E-5					
Np	Beef (cow)	1.0E-4						
Np	Beef (bull)	1.0E-4						
Np	Veal	3.0E-4						
Np	Pork	3.0E-4						
Np	Lamb	1.0E-3						
Np	Chicken	2.0E-4						
Np	Eggs	5.0E-3						
Pr	Cow milk	2.0E-5						
Pr	Sheep milk	2.0E-4						
Pr	Goat milk	2.0E-4						
Pr	Beef (cow)	3.0E-4						
Pr	Beef (bull)	3.0E-5						
Pr	Veal	1.0E-4						
Pr	Pork	2.0E-3						
Pr	Lamb	3.0E-3						
Pr	Chicken	3.0E-2						
Pr	Eggs	3.0E-3						
Pu	Cow milk	6.0E-5	1.0E-5					
Pu	Sheep milk	4.0E-4	1.0E-4					
Pu	Goat milk	4.0E-4						
Pu	Beef (cow)	6.0E-5	6.0E-5	1.3E-4	8.8E-8	3.0E-4	1.1E-6	2.5E+01
Pu	Beef (bull)	6.0E-5	6.0E-5	1.3E-4	8.8E-8	3.0E-4	1.1E-6	2.5E+01
Pu	Veal	2.0E-4	6.0E-5	1.3E-4	8.8E-8	3.0E-4	1.1E-6	2.5E+01

Element	FDMT Animal product	FDMT F_f or F_m	IAEA F_f or F_m AM	IAEA F_f or F_m ASD	IAEA F_f or F_m Min	IAEA F_f or F_m Max	IAEA F_f or F_m GM	IAEA F_f or F_m GSD
Pu	Pork	3.0E-4						
Pu	Lamb	7.0E-4	5.3E-5		2.0E-5	8.5E-5		
Pu	Chicken	2.0E-4						
Pu	Eggs	7.0E-3	1.2E-3		9.9E-6	2.3E-3		
Rb	Cow milk	3.0E-3						
Rb	Sheep milk	6.0E-2						
Rb	Goat milk	6.0E-2						
Rb	Beef (cow)	1.0E-2						
Rb	Beef (bull)	4.0E-2						
Rb	Veal	3.5E-1						
Rb	Pork	4.0E-1						
Rb	Lamb	5.0E-1						
Rb	Chicken	4.5E+00						
Rb	Eggs	3.0E-1						
Rh	Cow milk	1.0E-2						
Rh	Sheep milk	1.0E-2						
Rh	Goat milk	1.0E-2						
Rh	Beef (cow)	2.0E-3						
Rh	Beef (bull)	2.0E-3						
Rh	Veal	5.0E-3						
Rh	Pork	1.0E-2						
Rh	Lamb	2.0E-2						
Rh	Chicken	2.0E-2						
Rh	Eggs	2.0E-2						
Ru	Cow milk	1.0E-4	3.6E-5	5.3E-5	6.7E-7	1.4E-4	9.4E-6	8.5E+00

Element	FDMT Animal product	FDMT F_f or F_m	IAEA F_f or F_m AM	IAEA F_f or F_m ASD	IAEA F_f or F_m Min	IAEA F_f or F_m Max	IAEA F_f or F_m GM	IAEA F_f or F_m GSD
Ru	Sheep milk	1.0E-3						
Ru	Goat milk	1.0E-3						
Ru	Beef (cow)	1.0E-3	3.7E-3	2.3E-3	2.2E-3	6.4E-3	3.3E-3	1.8E+00
Ru	Beef (bull)	1.0E-3	3.7E-3	2.3E-3	2.2E-3	6.4E-3	3.3E-3	1.8E+00
Ru	Veal	2.0E-3	3.7E-3	2.3E-3	2.2E-3	6.4E-3	3.3E-3	1.8E+00
Ru	Pork	5.0E-3	3.0E-3					
Ru	Lamb	1.0E-2	2.1E-3		6.3E-4	3.6E-3		
Ru	*Lamb*	*1.0E-2*	*6.3E-4*					
Ru	Chicken	7.0E-3						
Ru	Eggs	6.0E-3	4.0E-3					
Sb	Cow milk	1.0E-4	5.2E-5	5.1E-5	2.0E-5	1.1E-4	3.8E-5	2.5E+00
Sb	Sheep milk	1.0E-3						
Sb	Goat milk	1.0E-3						
Sb	Beef (cow)	1.0E-3	1.2E-3		1.1E-3	1.3E-3		
Sb	Beef (bull)	1.0E-3	1.2E-3		1.1E-3	1.3E-3		
Sb	Veal	3.0E-3	1.2E-3		1.1E-3	1.3E-3		
Sb	Pork	5.0E-3						
Sb	Lamb	1.0E-2						
Sb	Chicken	1.0E-1						
Sb	Eggs	1.0E-1						
Sr	Cow milk	2.0E-3	1.5E-3	8.1E-4	3.4E-4	4.3E-3	1.3E-3	1.7E+00
Sr	Sheep milk	1.4E-2	3.0E-2	1.2E-2	1.3E-2	4.0E-2	2.7E-2	1.2E+00
Sr	Goat milk	1.4E-2	2.1E-2	2.0E-2	5.8E-3	8.1E-2	1.6E-2	2.0E+00
Sr	Beef (cow)	3.0E-4	2.1E-3	2.2E-3	2.0E-4	9.2E-3	1.3E-3	2.9E+00
Sr	Beef (bull)	3.0E-4	2.1E-3	2.2E-3	2.0E-4	9.2E-3	1.3E-3	2.9E+00

Element	FDMT Animal product	FDMT F_f or F_m	IAEA F_f or F_m AM	IAEA F_f or F_m ASD	IAEA F_f or F_m Min	IAEA F_f or F_m Max	IAEA F_f or F_m GM	IAEA F_f or F_m GSD
Sr	Veal	2.0E-3	2.1E-3	2.2E-3	2.0E-4	9.2E-3	1.3E-3	2.9E+00
Sr	Pork	2.0E-3	3.6E-3	2.7E-3	5.0E-4	8.0E-3	2.5E-3	2.7E+00
Sr	Lamb	3.0E-3	1.7E-3	7.5E-4	3.0E-4	4.0E-3	1.5E-3	1.7E+00
Sr	*Lamb*	*3.0E-3*	*2.6E-3*	*1.1E-3*	*1.1E-3*	*3.7E-3*	*2.4E-3*	*1.7E+00*
Sr	Chicken	4.0E-2	2.3E-2	1.2E-2	7.0E-3	4.1E-2	2.0E-2	1.8E+00
Sr	Eggs	2.0E-1	3.7E-1	1.4E-1	2.2E-1	6.4E-1	3.5E-1	1.4E+00
Tc	Cow milk	1.0E-4						
Tc	Sheep milk	1.0E-3						
Tc	Goat milk	1.0E-3						
Tc	Beef (cow)	5.0E-4						
Tc	Beef (bull)	5.0E-4						
Tc	Veal	1.0E-3						
Tc	Pork	1.0E-3						
Tc	Lamb	5.0E-3						
Tc	Chicken	1.0E-1						
Tc	Eggs	1.0E+00						
Te	Cow milk	5.0E-4	4.5E-4	2.9E-4	7.8E-5	1.0E-3	3.4E-4	2.4E+00
Te	Sheep milk	4.0E-3	2.9E-3					
Te	Goat milk	4.0E-3	4.4E-3					
Te	Beef (cow)	7.0E-3	7.0E-3					
Te	Beef (bull)	7.0E-3	7.0E-3					
Te	Veal	2.0E-2	7.0E-3					
Te	Pork	3.0E-2						
Te	Lamb	7.0E-2						
Te	Chicken	6.0E-1	6.0E-1					

Element	FDMT Animal product	FDMT F_f or F_m	IAEA F_f or F_m AM	IAEA F_f or F_m ASD	IAEA F_f or F_m Min	IAEA F_f or F_m Max	IAEA F_f or F_m GM	IAEA F_f or F_m GSD
Te	Eggs	5.0E+00	5.1E+00					
Y	Cow milk	1.0E-5						
Y	Sheep milk	1.0E-4						
Y	Goat milk	1.0E-2	2.0E-5					
Y	Beef (cow)	1.0E-3						
Y	Beef (bull)	1.0E-3						
Y	Veal	3.0E-3						
Y	Pork	5.0E-3						
Y	Lamb	1.0E-2						
Y	Chicken	1.0E-2						
Y	Eggs	2.0E-3						
Zr	Cow milk	6.0E-7	7.1E-6	6.9E-6	5.5E-7	1.7E-5	3.6E-6	4.3E+00
Zr	Sheep milk	6.0E-6						
Zr	Goat milk	6.0E-6	5.5E-6					
Zr	Beef (cow)	1.0E-6	1.2E-6					
Zr	Beef (bull)	1.0E-6	1.2E-6					
Zr	Veal	3.0E-6	1.2E-6					
Zr	Pork	5.0E-6						
Zr	Lamb	1.0E-5						
Zr	Chicken	6.0E-5	6.0E-5					
Zr	Eggs	2.0E-4	2.0E-4					

Beef (cow) and Beef (bull) are both compared to IAEA ‘cow meat’. Shaded cells signify that all the data are obtained from the stable element/animal nutrition literature. IAEA data used for Sb for Beef (bull) is described as being for ‘young animals’. IAEA data for Na for chicken is for duck. IAEA data for chicken for Co, Cs and Sr also includes data for duck. IAEA data for eggs for Cs and Sr also includes data for duck. IAEA Co data for eggs is for duck eggs.

Appendix 3 – A comparison of outputs from ECOSYS-87 implemented in EXCEL with the new implementation in ECOLEGO

This appendix presents the results of the calculations of activity concentrations in foodstuffs for the two case studies considered.

Wet deposition case study

Results of radionuclide concentrations in different foodstuffs are presented in Figures A3.1-A3.10.

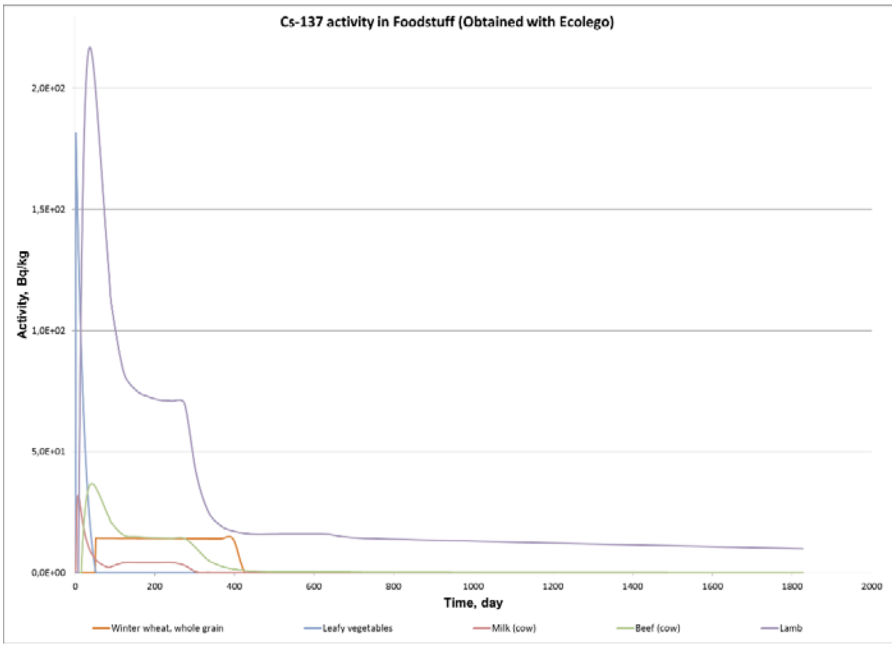


Figure A3.1 Cs-137 concentration in foodstuffs obtained with ECOLEGO for the wet deposition case study.

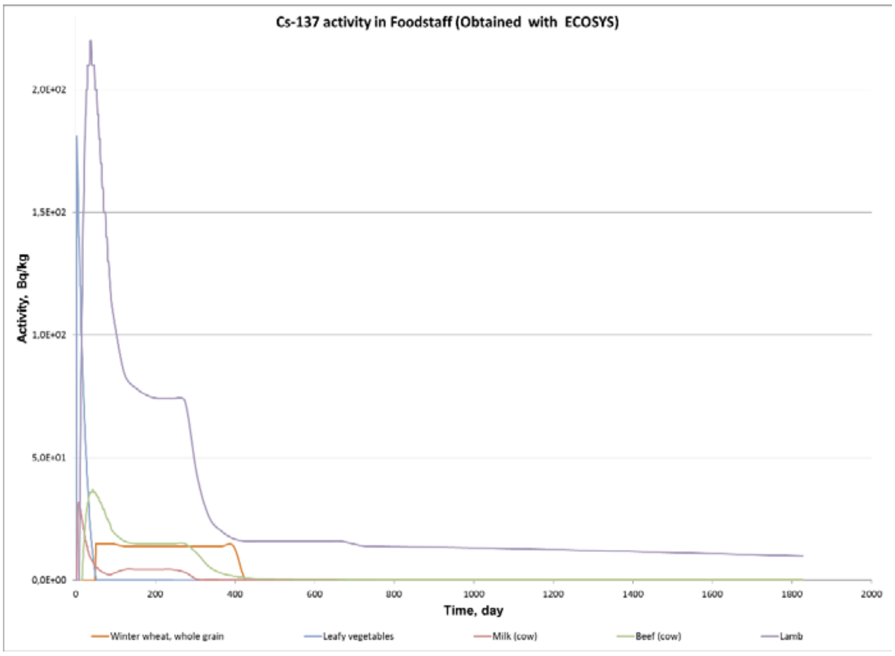


Figure A3.2 Cs-137 concentration in foodstuffs obtained with ECOSYS-87 for the wet deposition case study.

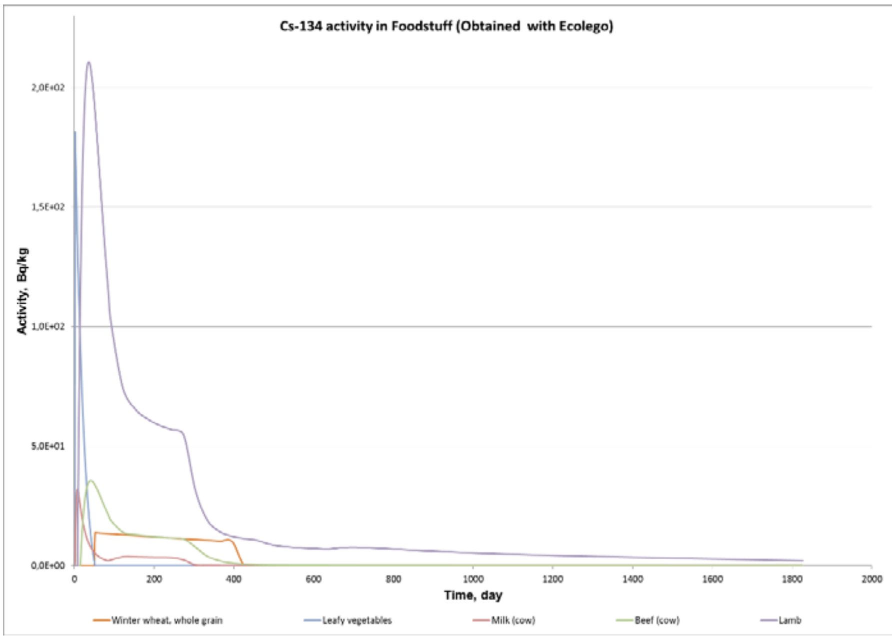


Figure A3.3 Cs-134 concentration in foodstuff obtained with ECOLEGO for the wet deposition case study.

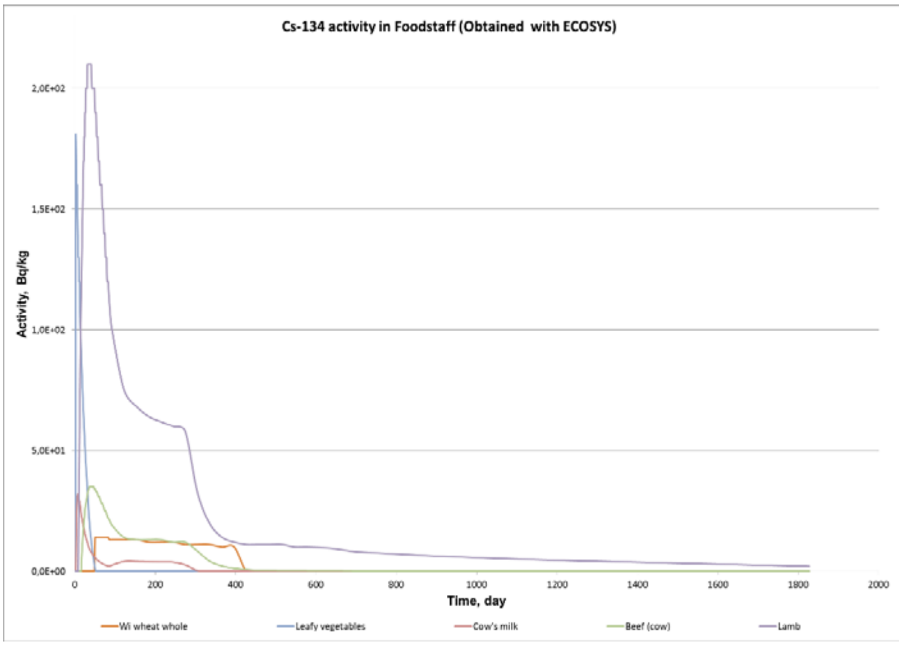


Figure A3.4 Cs-134 concentration in foodstuff obtained with ECOSYS-87 for the wet deposition case study.

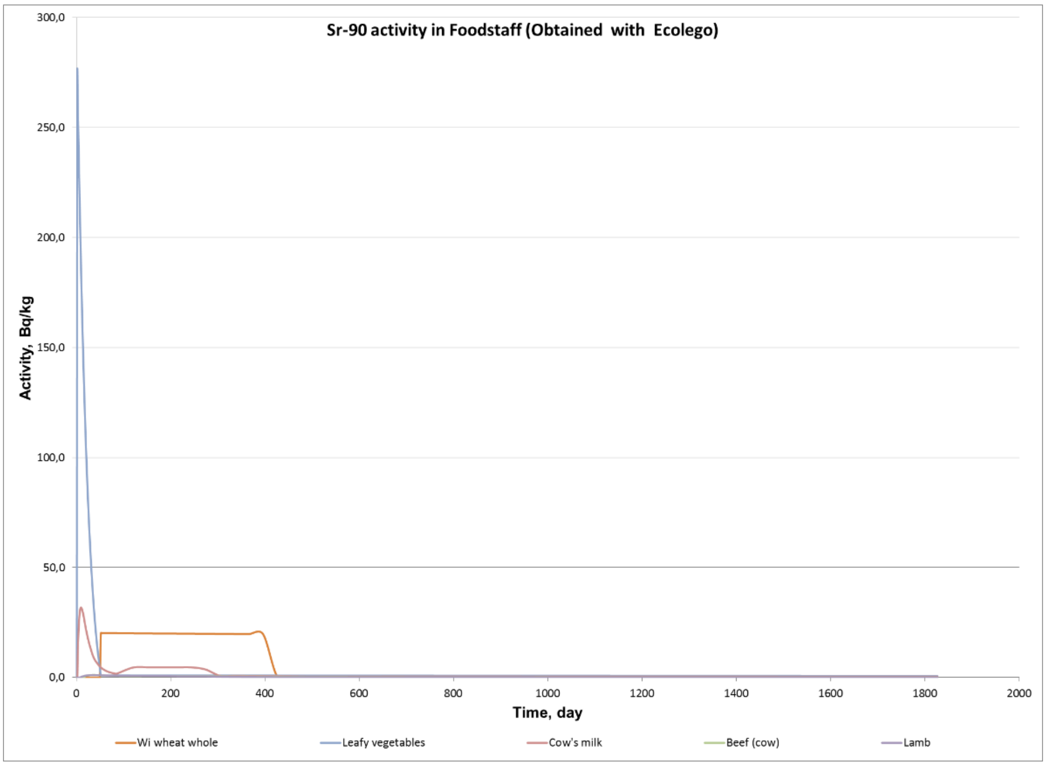


Figure A3.5 Sr-90 concentration in foodstuff obtained with ECOLEGO for the wet deposition case study.

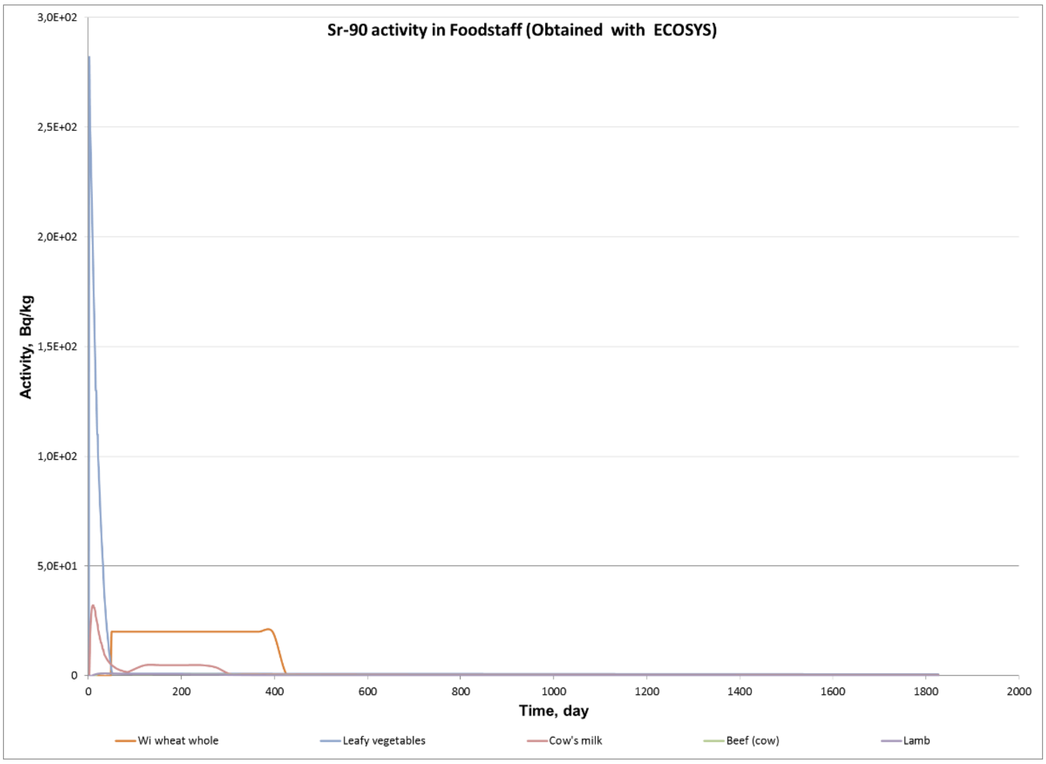


Figure A3.6 Sr-90 concentration in foodstuff obtained with ECOSYS-87 for the wet deposition case study.

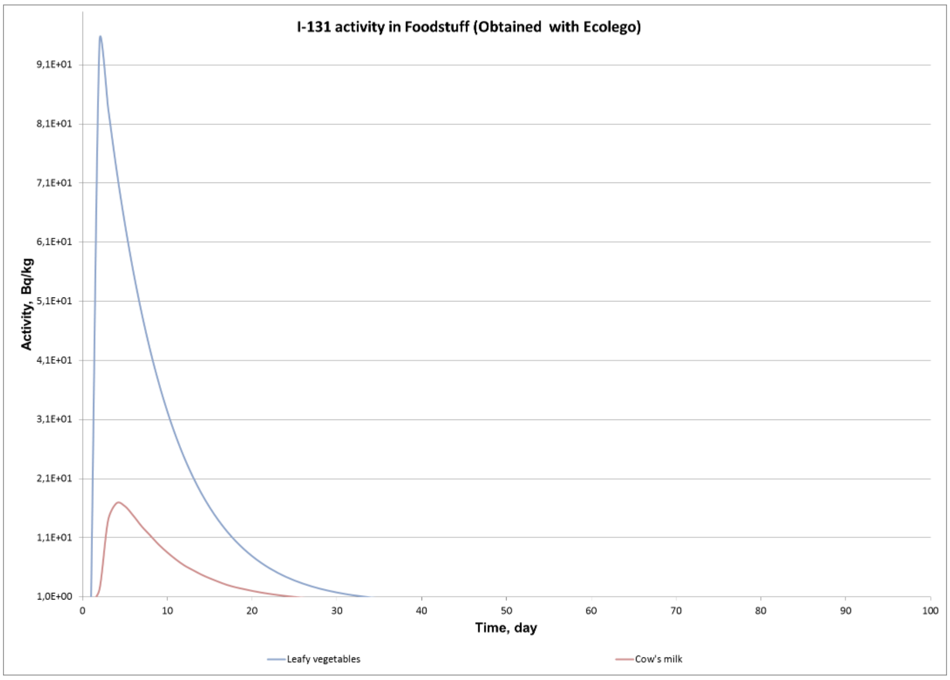


Figure A3.7 I-131 concentration in foodstuff obtained with ECOLEGO for the wet deposition case study.

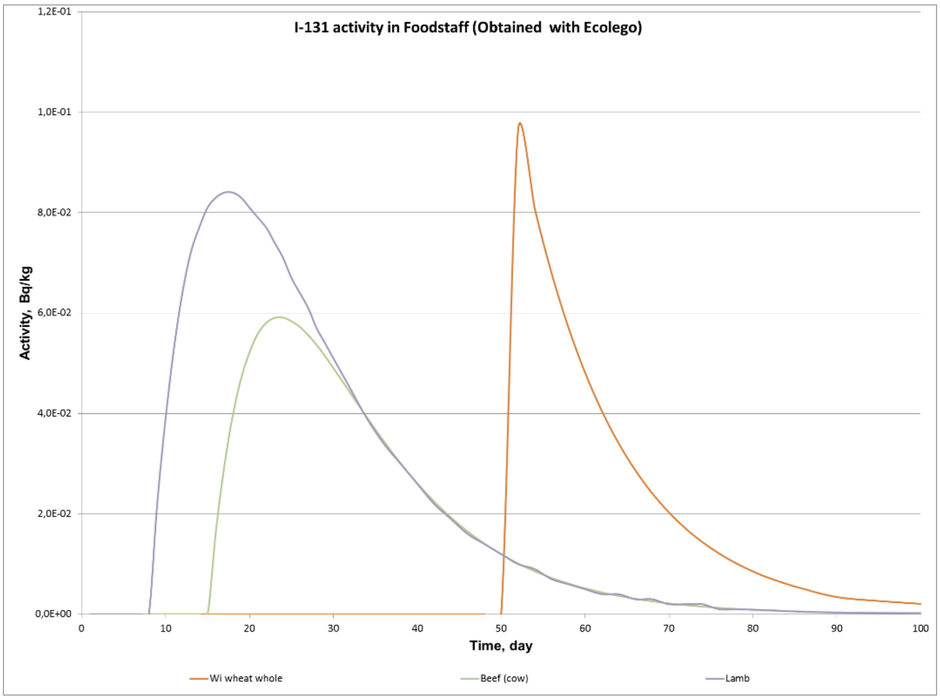


Figure A3.8 I-131 concentration in foodstuff obtained with ECOLEGO for the wet deposition case study.

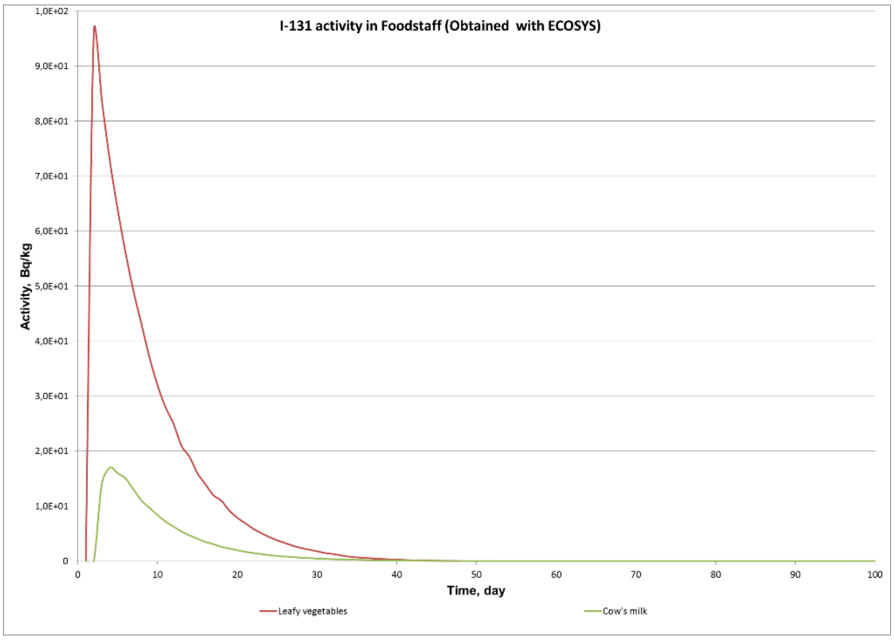


Figure A3.9 I-131 concentration in foodstuff obtained with ECOSYS-87 for the wet deposition case study.

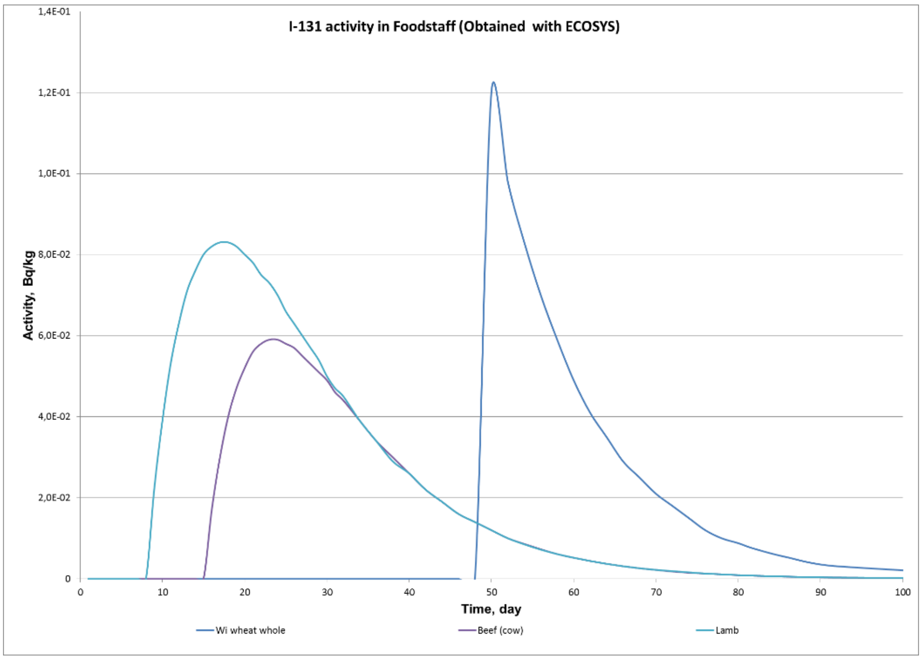


Figure A3.10 I-131 concentration in foodstuff obtained with ECOSYS-87 for the wet deposition case study.

Maximum radionuclide concentrations and concentrations at the end of 5-year period in all foodstuffs are shown in Tables A3.1-A3.4.

Table A3.1 Cs-137 concentrations in foodstuffs for the wet deposition case study.

Foodstuff	**Maximum concentration (Bq/kg)**		**Concentration at the end of 5-years period (Bq/kg)**	
	ECOSYS-87 EXCEL	**ECOLEGO**	**ECOSYS-87 EXCEL**	**ECOLEGO**
Winter wheat	15	14	3.5E-2	3.5E-2
Leafy vegetables	180	180	2.8E-2	2.8E-2
Cow`s milk	32	32	4.6E-2	4.6E-2
Beef cow	37	37	1.5E-1	1.6E-1
Lamb	220	220	9.9	10

Table A3.2 Cs-134 concentrations in foodstuffs for the wet deposition case study.

Foodstuff	**Maximum concentration (Bq/kg)**		**Concentration at the end of 5-years period (Bq/kg)**	
	ECOSYS-87 EXCEL	**ECOLEGO**	**ECOSYS-87 EXCEL**	**ECOLEGO**
Winter wheat	14	14	7.2E-3	7.4E-3
Leafy vegetables	180	180	5.8E-3	5.8E-3
Cow`s milk	32	32	9.6E-3	9.7E-3
Beef cow	35	36	3.0E-2	3.0E-2
Lamb	210	210	2.0	2.0

Table A3.3 Sr-90 concentrations in foodstuff for the wet deposition case study.

Foodstuff	**Maximum concentration (Bq/kg)**		**Concentration at the end of 5-years period (Bq/kg)**	
	ECOSYS-87 EXCEL	**ECOLEGO**	**ECOSYS-87 EXCEL**	**ECOLEGO**
Winter wheat	20	20	4.0E-1	4.0E-1
Leafy vegetables	280	270	6.4E-1	6.4E-1
Cow`s milk	32	33	3.2E-1	3.2E-1
Beef cow	1.1	1.2	4.7E-2	4.9E-2
Lamb	1.1	1.1	5.2E-2	5.2E-2

Table A3.4 I-131 concentrations in foodstuff for the wet deposition case study.

Foodstuff	**Maximum concentration (Bq/kg)**		**Concentration at the end of 5-years period (Bq/kg)**	
	ECOSYS-87 EXCEL	**ECOLEGO**	**ECOSYS-87 EXCEL**	**ECOLEGO**
Winter wheat	1.2E-1	9.6E-2	0	0
Leafy vegetables	96	95	0	0
Cow`s milk	17	17	0	0
Beef cow	5.9E-2	5.9E-2	0	0
Lamb	8.3E-2	8.4E-2	0	0

Dry deposition Case Study

The results of radionuclide concentrations in different foodstuffs are presented in Figures A3.11-A3.20.

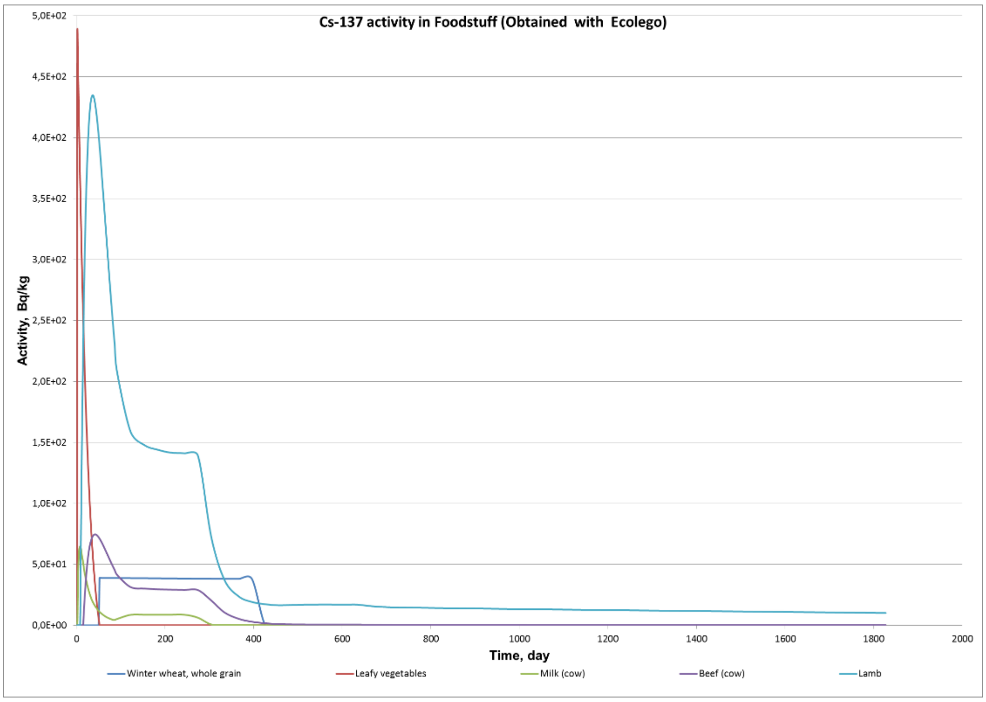


Figure A3.11 Cs-137 concentration in foodstuff obtained with ECOLEGO for the dry deposition case study

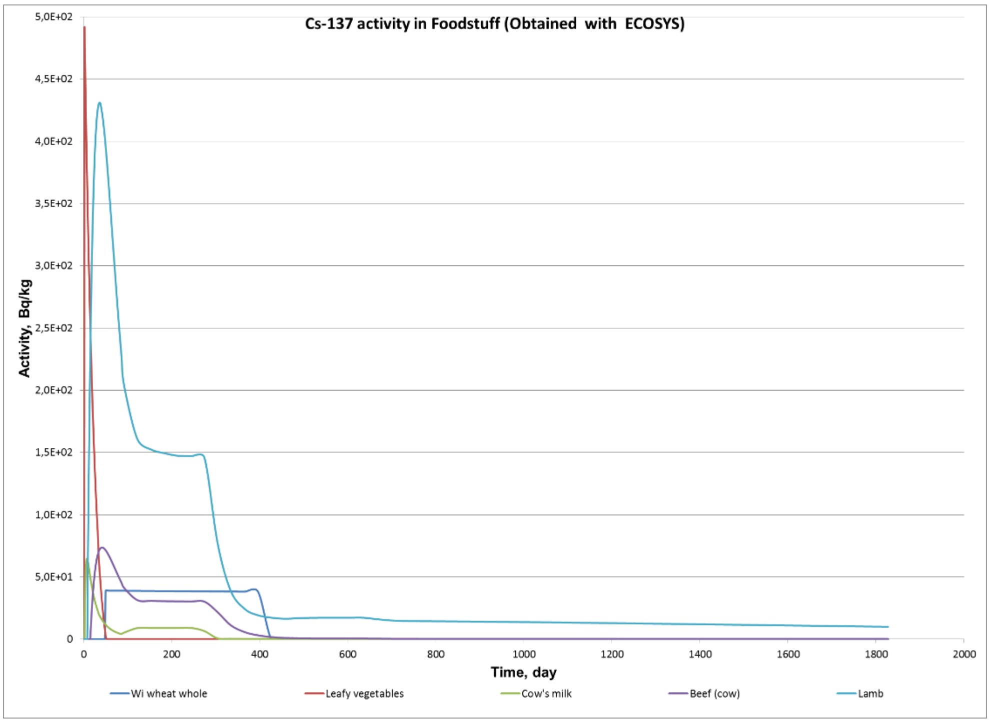


Figure A3.12 Cs-137 concentration in foodstuff obtained with ECOSYS-87 for the dry deposition case study

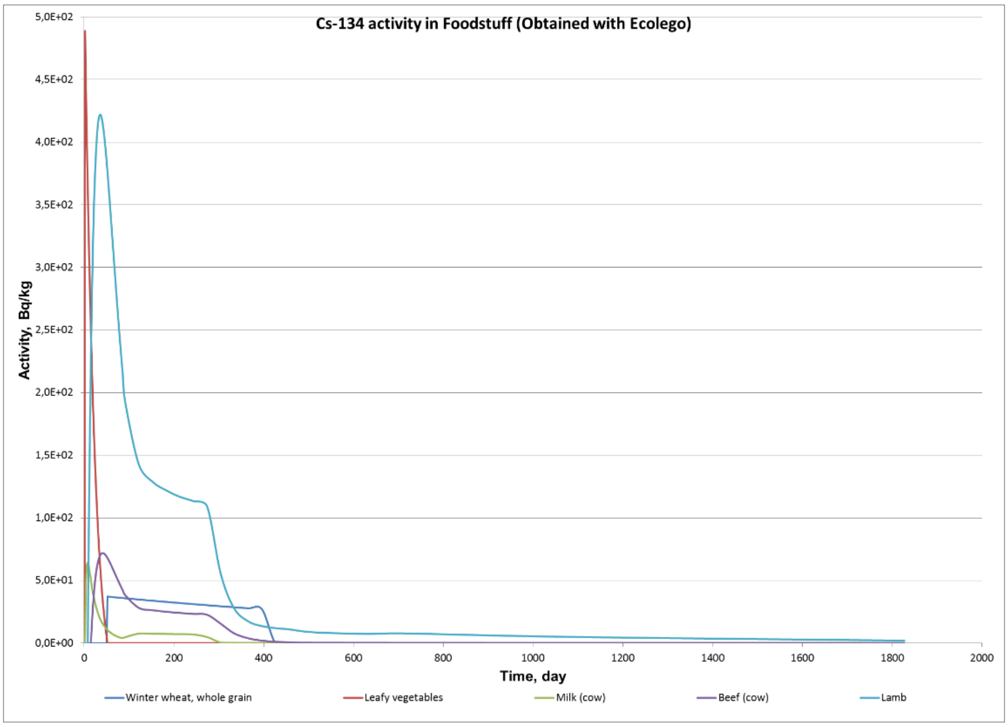


Figure A3.13 Cs-134 concentration in foodstuff obtained with ECOLEGO for the dry deposition case study

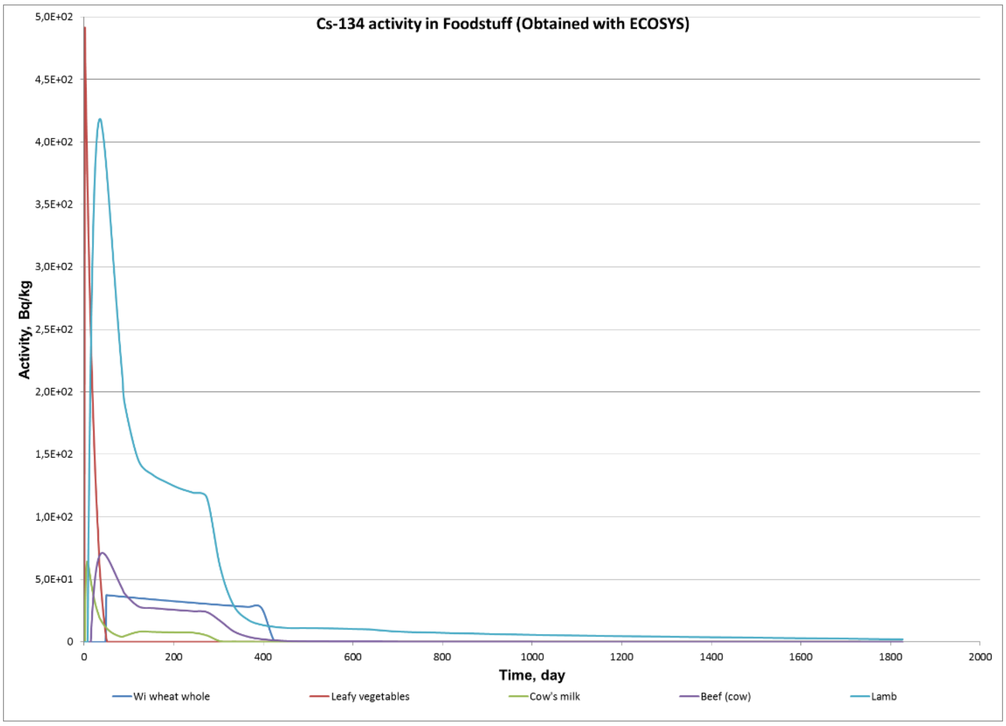


Figure A3.14 Cs-134 concentration in foodstuff obtained with ECOSYS-87 for the dry deposition case study

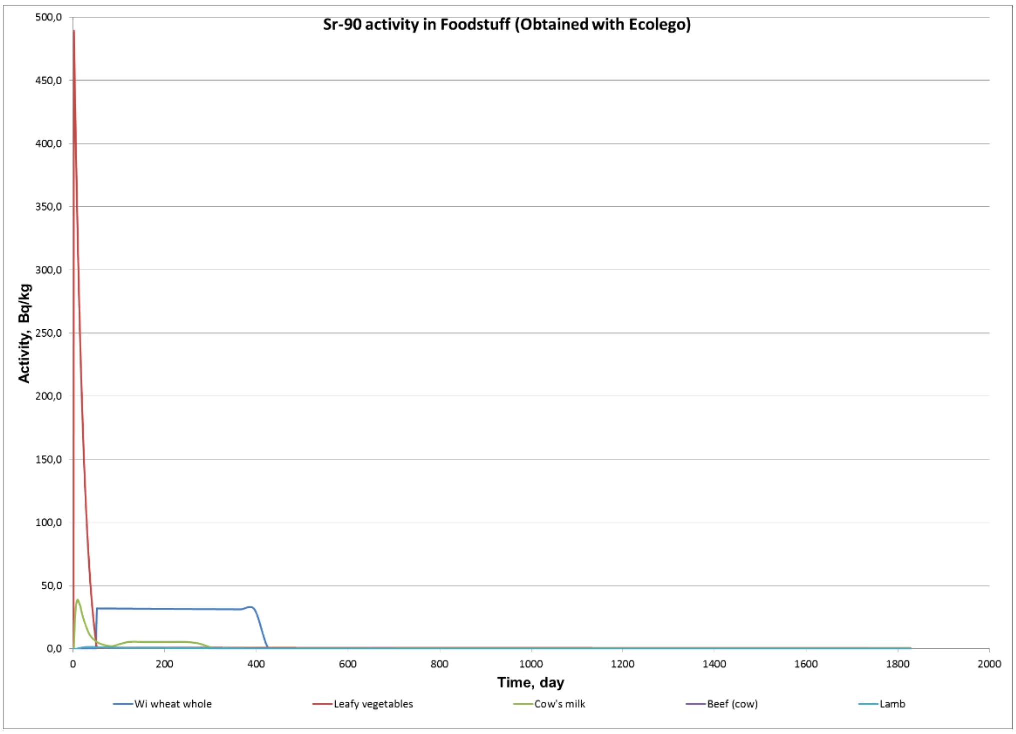


Figure A3.15 Sr-90 concentration in foodstuff obtained with ECOLEGO for the dry deposition case study

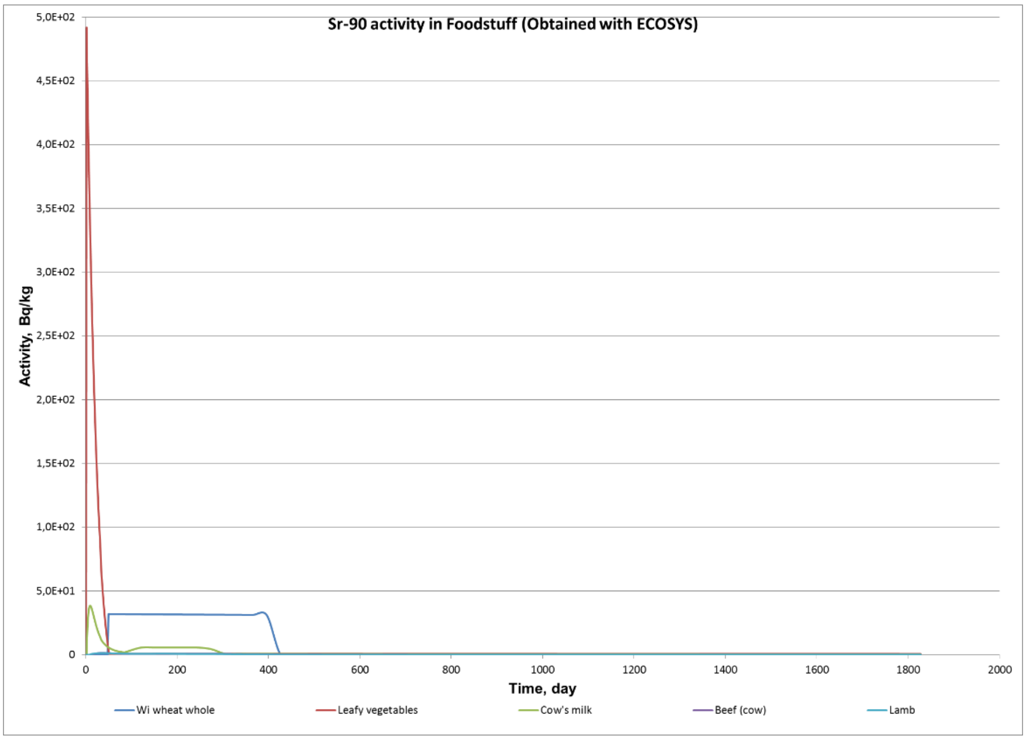


Figure A3.16 Sr-90 concentration in foodstuff obtained with ECOSYS-87 for the dry deposition case study

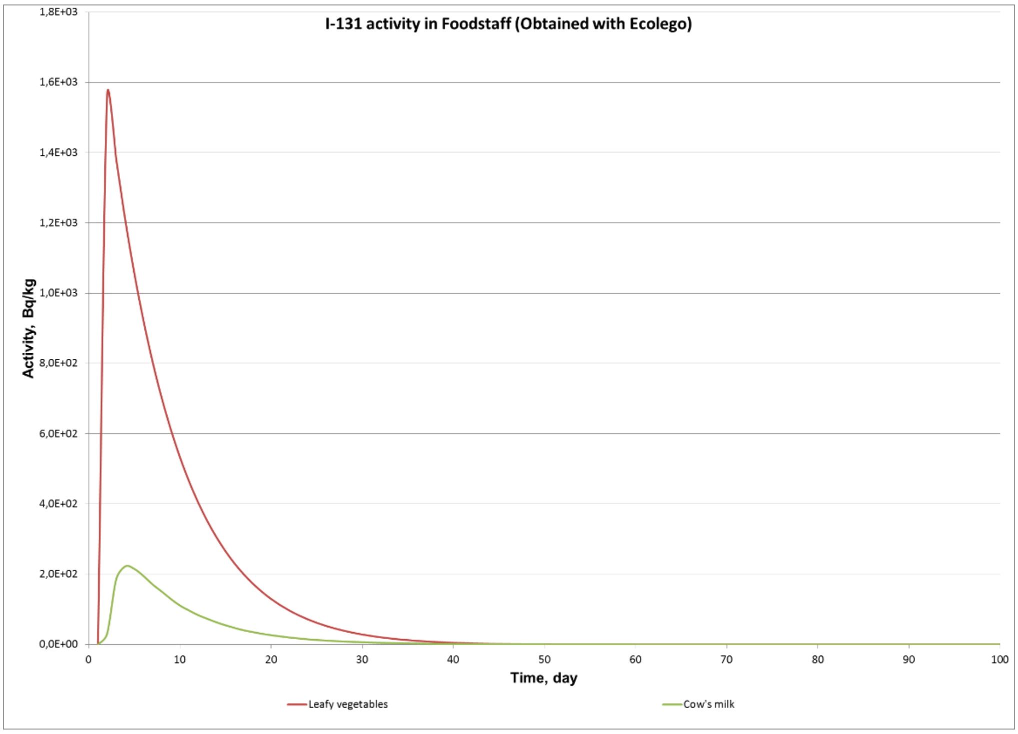


Figure A3.17 I-131 concentration in leafy vegetables and cow's milk obtained with ECOLEGO for the dry deposition case study

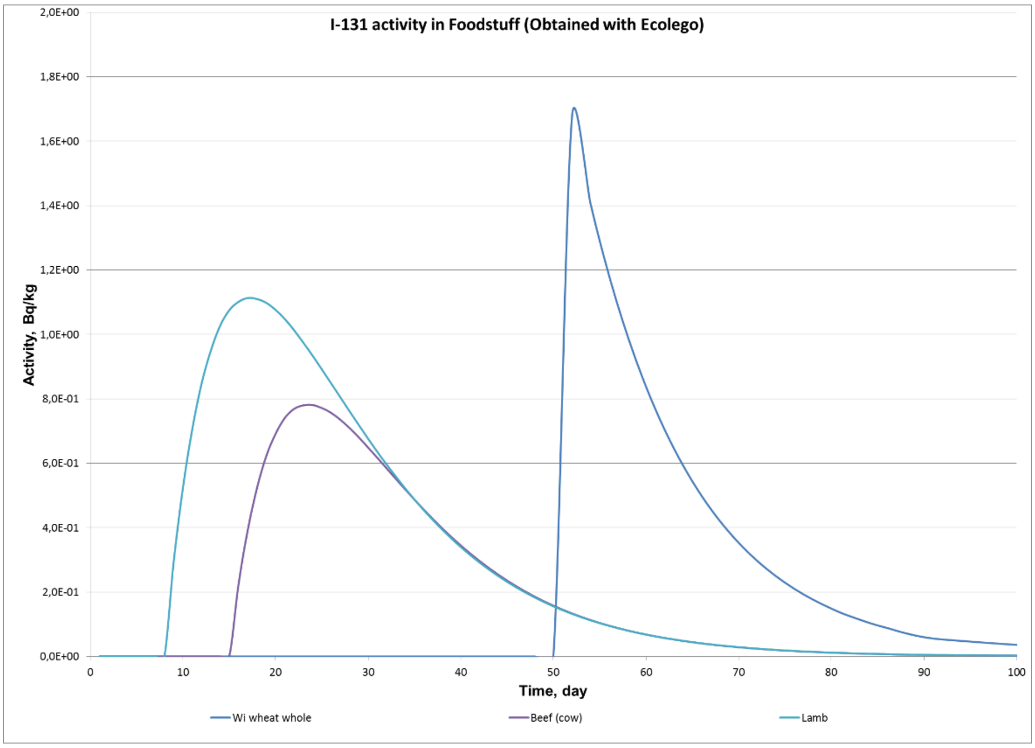


Figure A3.18 I-131 concentration in winter wheat, beef and lamb obtained with ECOLEGO for the dry deposition case study

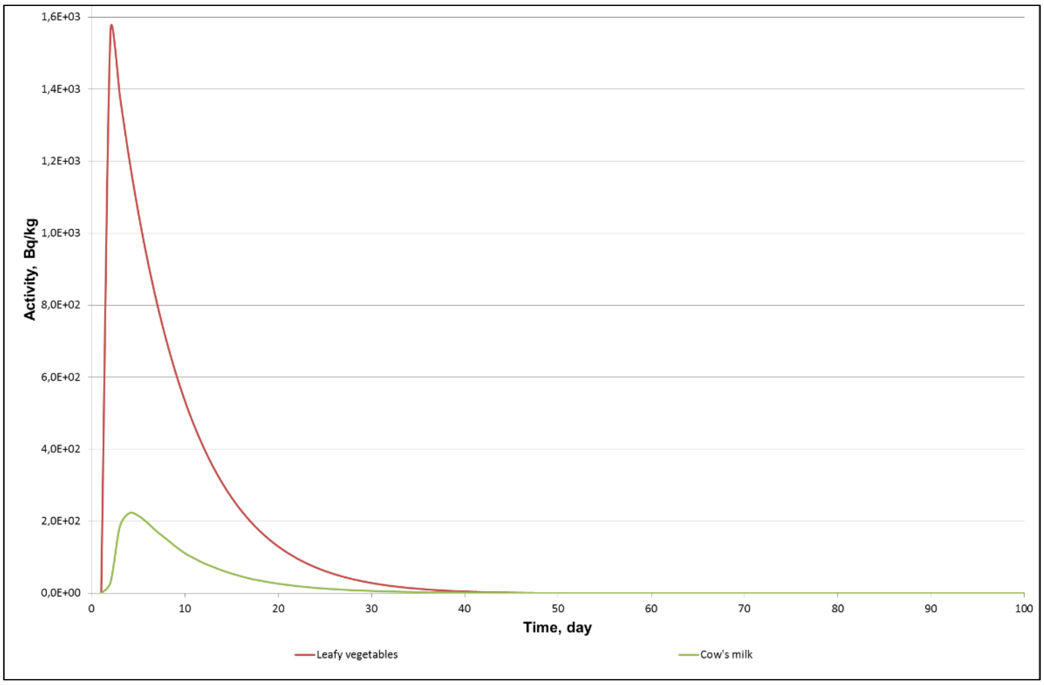


Figure A3.19 I-131 concentration in leafy vegetables and cow's milk obtained with ECOSYS-87 for the dry deposition case study.

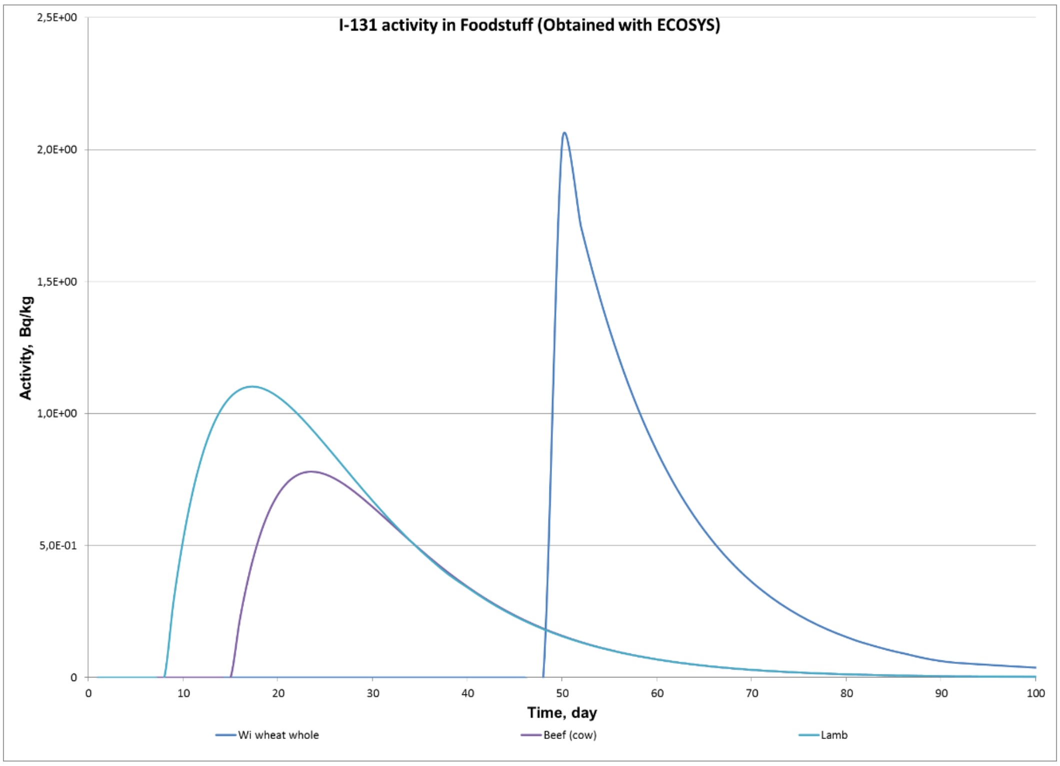


Figure A3.20 I-131 concentration in winter wheat, beef and lamb obtained with ECOSYS-87 for the dry deposition case study

Maximum radionuclide concentration and concentration at the end of 5-year period in all foodstuff are shown in Tables A3.5-A3.8.

Table A3.5 Cs-137 concentrations in foodstuff for the dry deposition case study

Foodstuff	**Maximum concentration (Bq/kg)**		**Concentration at the end of 5-years period (Bq/kg)**	
	ECOSYS-87 EXCEL	**ECOLEGO**	**ECOSYS-87 EXCEL**	**ECOLEGO**
Winter wheat	39	39	3.5E-2	3.6E-2
Leafy vegetables	490	490	2.8E-2	2.8E-2
Cow`s milk	65	65	4.7E-2	4.7E-2
Beef cow	74	75	1.6E-1	1. 6E-1
Lamb	430	430	10	10

Table A3.6 Cs-134 concentrations in foodstuff for the dry deposition case study

Foodstuff	**Maximum concentration (Bq/kg)**		**Concentration at the end of 5-years period (Bq/kg)**	
	ECOSYS-87 EXCEL	**ECOLEGO**	**ECOSYS-87 EXCEL**	**ECOLEGO**
Winter wheat	37	37	7.4E-3	7.5E-3
Leafy vegetables	490	490	5.9E-3	5.9E-3
Cow`s milk	64	64	9.7E-3	9.9E-3
Beef cow	71	72	3.1E-2	3.0E-2
Lamb	420	420	2.0	2.1

Table A3.7 Sr-90 concentrations in foodstuff for the dry deposition case study

Foodstuff	**Maximum concentration (Bq/kg)**		**Concentration at the end of 5-years period (Bq/kg)**	
	ECOSYS-87 EXCEL	**ECOLEGO**	**ECOSYS-87 EXCEL**	**ECOLEGO**
Winter wheat	32	32	4.1E-1	4.1E-1
Leafy vegetables	490	490	6.5E-1	6.5E-1
Cow`s milk	38	39	3.2E-1	3.2E-1
Beef cow	1.4	1.4	4.8E-2	5.0E-2
Lamb	1.3	1.3	5.3E-2	5.3E-2

Table A3.8 I-131 concentrations in foodstuff for the dry deposition case study

Foodstuff	**Maximum concentration (Bq/kg)**		**Concentration at the end of 5-years period (Bq/kg)**	
	ECOSYS-87 EXCEL	**ECOLEGO**	**ECOSYS-87 EXCEL**	**ECOLEGO**
Winter wheat	2.0	1.7	0	0
Leafy vegetables	1600	1600	0	0
Cow`s milk	220	220	0	0
Beef cow	7.8E-1	7.8E-1	0	0
Lamb	1.1	1.1	0	0

Appendix 4 – Parameters values – original FDMT defaults, updated values and distributions

Table A4.1 Deposition parameters

Parameter symbol	**Parameter description**	**Dependencies**	**New default (Old default)**	**Distribution*/Comment**	**Reference**
$S_{i,j}$	Retention coefficient (mm) of radionuclide i on plant type j	Cs-137, Beet	0.3 (0.3)	norm(0.3,0.3,0,infinity)	See main text
		I-131, Beet	0.15 (0.15)	norm(0.15,0.15,0,infinity)	See main text
		Sr-90, Beet	0.6 (0.6)	norm(0.6,0.6,0,infinity)	See main text
		Cs-137, Beet_leaves	0.3 (0.3)	norm(0.3,0.3,0,infinity)	See main text
		I-131, Beet_leaves	0.15 (0.15)	norm(0.15,0.15,0,infinity)	See main text
		Sr-90, Beet_leaves	0.6 (0.6)	norm(0.6,0.6,0,infinity)	See main text
		Cs-137, Berries	0.3 (0.3)	norm(0.3,0.3,0,infinity)	See main text
		I-131, Berries	0.15 (0.15)	norm(0.15,0.15,0,infinity)	See main text
		Sr-90, Berries	0.6 (0.6)	norm(0.6,0.6,0,infinity)	See main text
		Cs-137, Corn_cobs	0.2 (0.2)	norm(0.2,0.2,0,infinity)	See main text
		I-131, Corn_cobs	0.1 (0.1)	norm(0.1,0.1,0,infinity)	See main text
		Sr-90, Corn_cobs	0.4 (0.4)	norm(0.4,0.4,0,infinity)	See main text
		Cs-137, Fruit	0.3 (0.3)	norm(0.3,0.3,0,infinity)	See main text
		I-131, Fruit	0.15 (0.15)	norm(0.15,0.15,0,infinity)	See main text
		Sr-90, Fruit	0.6 (0.6)	norm(0.6,0.6,0,infinity)	See main text
		Cs-137, Fruit_vegetables	0.3 (0.3)	norm(0.3,0.3,0,infinity)	See main text
		I-131, Fruit_vegetables	0.15 (0.15)	norm(0.15,0.15,0,infinity)	See main text
		Sr-90, Fruit_vegetables	0.6 (0.6)	norm(0.6,0.6,0,infinity)	See main text
		Cs-137, GrassE	0.2 (0.2)	norm(0.2,0.2,0,infinity)	See main text

Parameter symbol	Parameter description	Dependencies	New default (Old default)	Distribution*/Comment	Reference
		I-131, GrassE	0.1 (0.1)	norm(0.1,0.1,0,infinity)	See main text
		Sr-90, GrassE	0.4 (0.4)	norm(0.4,0.4,0,infinity)	See main text
		Cs-137, GrassI	0.2 (0.2)	norm(0.2,0.2,0,infinity)	See main text
		I-131, GrassI	0.1 (0.1)	norm(0.1,0.1,0,infinity)	See main text
		Sr-90, GrassI	0.4 (0.4)	norm(0.4,0.4,0,infinity)	See main text
		Cs-137, Lawn	0.2 (0.2)	norm(0.2,0.2,0,infinity)	See main text
		I-131, Lawn	0.1 (0.1)	norm(0.1,0.1,0,infinity)	See main text
		Sr-90, Lawn	0.4 (0.4)	norm(0.4,0.4,0,infinity)	See main text
		Cs-137, Leafy_vegetables	0.3 (0.3)	norm(0.3,0.3,0,infinity)	See main text
		I-131, Leafy_vegetables	0.15 (0.15)	norm(0.15,0.15,0,infinity)	See main text
		Sr-90, Leafy_vegetables	0.6 (0.6)	norm(0.6,0.6,0,infinity)	See main text
		Cs-137, Maize	0.2 (0.2)	norm(0.2,0.2,0,infinity)	See main text
		I-131, Maize	0.1 (0.1)	norm(0.1,0.1,0,infinity)	See main text
		Sr-90, Maize	0.4 (0.4)	norm(0.4,0.4,0,infinity)	See main text
		Cs-137, Oats	0.2 (0.2)	norm(0.2,0.2,0,infinity)	See main text
		I-131, Oats	0.1 (0.1)	norm(0.1,0.1,0,infinity)	See main text
		Sr-90, Oats	0.4 (0.4)	norm(0.4,0.4,0,infinity)	See main text
		Cs-137, Potatoes	0.3 (0.3)	norm(0.3,0.3,0,infinity)	See main text
		I-131, Potatoes	0.15 (0.15)	norm(0.15,0.15,0,infinity)	See main text
		Sr-90, Potatoes	0.6 (0.6)	norm(0.6,0.6,0,infinity)	See main text
		Cs-137, Root_vegetables	0.3 (0.3)	norm(0.3,0.3,0,infinity)	See main text
		I-131, Root_vegetables	0.15 (0.15)	norm(0.15,0.15,0,infinity)	See main text
		Sr-90, Root_vegetables	0.6 (0.6)	norm(0.6,0.6,0,infinity)	See main text

Parameter symbol	Parameter description	Dependencies	New default (Old default)	Distribution[*]/Comment	Reference
		Cs-137, Rye	0.2 (0.2)	norm(0.2,0.2,0,infinity)	See main text
		I-131, Rye	0.1 (0.1)	norm(0.1,0.1,0,infinity)	See main text
		Sr-90, Rye	0.4 (0.4)	norm(0.4,0.4,0,infinity)	See main text
		Cs-137, Spring_barley	0.2 (0.2)	norm(0.2,0.2,0,infinity)	See main text
		I-131, Spring_barley	0.1 (0.1)	norm(0.1,0.1,0,infinity)	See main text
		Sr-90, Spring_barley	0.4 (0.4)	norm(0.4,0.4,0,infinity)	See main text
		Cs-137, Spring_wheat	0.2 (0.2)	norm(0.2,0.2,0,infinity)	See main text
		I-131, Spring_wheat	0.1 (0.1)	norm(0.1,0.1,0,infinity)	See main text
		Sr-90, Spring_wheat	0.4 (0.4)	norm(0.4,0.4,0,infinity)	See main text
		Cs-137, Winter_barley	0.2 (0.2)	norm(0.2,0.2,0,infinity)	See main text
		I-131, Winter_barley	0.1 (0.1)	norm(0.1,0.1,0,infinity)	See main text
		Sr-90, Winter_barley	0.4 (0.4)	norm(0.4,0.4,0,infinity)	See main text
		Cs-137, Winter_wheat	0.2 (0.2)	norm(0.2,0.2,0,infinity)	See main text
		I-131, Winter_wheat	0.1 (0.1)	norm(0.1,0.1,0,infinity)	See main text
		Sr-90, Winter_wheat	0.4 (0.4)	norm(0.4,0.4,0,infinity)	See main text

[*] Normal = norm(mean, mean,standard deviation,truncated min,truncated max); Lognormal = logn(mean,standard deviation,truncated min,truncated max); Triangular = triang(min,max,mode, truncated min,truncated max); Uniform =unif(min,max, truncated min,truncated max).

Table A4.2 Radionuclides with plant specific parameters.

Parameter symbol	**Parameter description**	**Dependencies**	**New default (Old default)**	**Distribution[*]/Comment**	**Reference**
R_j	*Mass load of soil on plant j (g soil per g plant)*	Grass	0 (1E-3)	Set to 0 to avoid 'double accounting' - For animal enpoint : soil ingestion included in S_j	
		All crops[1]	2.7E-3(1E-3)	unif(3.3E-4, 5E-3,0,infinity)	
lambda_wi	*Weathering rate from plants (d^{-1})*	Cs, grass	0.047 (0.0277)	logn(0.05,0.019,0,infinity)	Andersson et al. (2011)
		I, grass	0.07 (0.0277)	logn(0.075,0.029,0,infinity)	Andersson et al. (2011)
		Sr, grass	0.047 (0.0277)	logn(0.05,0.019,0,infinity)	Andersson et al. (2011)
		Cs, (Beet_leaves, Leafy_vegetables, Maize)	0.026 (0.0277)	logn(0.03,0.016,0,infinity)	Andersson et al. (2011)
		I, (Beet_leaves, Leafy_vegetables, Maize)	0.056 (0.0277)	logn(0.067,0.044,0,infinity)	Andersson et al. (2011)
		Sr, (Beet_leaves, Leafy_vegetables, Maize)	0.026 (0.0277)	logn(0.03,0.016,0,infinity)	Andersson et al. (2011)
f_e_i	*Enrichment factor for radionuclide I, (unitless)*	Cs	0.25 (3*)	triang(0,04,0.4,0.25, 0,infinity)	See main text: *1 used in ECOLEGO
		I	1 (1)		See main text
		Sr	2 (3*)	triang(1,3,2,0,infinity)	See main text; *1 used in ECOLEGO
TF_ij	*Soil-plant transfer factor for radionuclide, (unitless)*	Cs, Beet_leaves	0.0056 (0.03)	logn(0.01088,0.0192,0,infinity)	IAEA (2009)
		I, Beet_leaves	1.23E-3 (0.1)	logn(2.08E-3,1.92E-3,0,infinity)	IAEA (2009)
		Sr, Beet_leaves	1.15E-1 (0.8)	logn(2.4E-1,2.24E-1,0,infinity)	IAEA (2009)
		Cs, Leafy_vegetables	6.00E-3 (0.02)	logn(1.7E-2,2.1E-2,0,infinity)	IAEA (2009)
		I, Leafy_vegetables	6.50E-4 (0.1)	logn(1.6E-3,2.9E-3,0,infinity)	IAEA (2009)
		Sr, Leafy_vegetables	7.60E-2 (0.4)	logn(1.9E-1,1.8E-1,0,infinity)	IAEA (2009)
		Cs, Maize	1.83E-2 (0.02)	logn(3E-2,2.75E-2,0,infinity)	IAEA (2009)

Parameter symbol	Parameter description	Dependencies	New default (Old default)	Distribution*/Comment	Reference
		I, Maize	1.30E-2 (0.1)	logn(2.75E-2,4.5E-2,0,infinity) *for cereal stem and shoots	IAEA (2009)
		Sr, Maize	1.83E-1 (0.3)	logn(2-48E-1,1.9E-1,0,infinity)	IAEA (2009)
		Cs, Beet	6.72E-3 (0.01)	logn(0.012,1.76E-2,0,infinity)	IAEA (2009)
		I, Beet	1.23E-3 (0.1)	logn(2.08E-3,192E-3,0,infinity)	IAEA (2009)
		Sr, Beet	0.1152 (0.4)	logn(0.24,0.224,0,infinity)	IAEA (2009)
		Cs, Corn_cobs	6.27E-3 (0.01)	logn(1.05E-2,1.08E-2,0,infinity)	IAEA (2009)
		I, Corn_cobs	1.20E-4 (0.1)	logn(2.66E-4,5.32E-4,0,infinity)	IAEA (2009)
		Sr, Corn_cobs	6.08E-2 (0.2)	logn(1.12E-1,1.16E-2,0,infinity)	IAEA (2009)
		Cs, Fruit	8.70E-4 (0.02)	logn(2.25E-3,3.3e-3,0,infinity	IAEA (2009)
		I, Fruit	9.45E-4 (0.1)	logn(1.80E-3,1.8E-3,0,infinity)	IAEA (2009)
		Sr, Fruit	2.55E-3 (0.1)	logn(3.75E-3,2.85E-3,0,infinity)	IAEA (2009)
		Cs, Oats	2.52E-2 (0.02)	logn(6.61E-2,1.31E-1,0,infinity)	IAEA (2009)
		I, Oats	5.48E-4 (0.1)	logn(1.33E-4,2.44E-3,0,infinity)	IAEA (2009)
		Sr, Oats	9.57E-2 (0.2)	logn(1.57E-1,1.65E-1,0,infinity)	IAEA (2009)
		Cs, Potatoes	1.18E-2 (0.01)	logn(2.1E-2,2.52E-2,0,infinity)	IAEA (2009)
		I, Potatoes	0.021 (0.1)		IAEA (2009)
		Sr, Potatoes	3.36E-2 (0.05)	logn(5.04E-2,4.62E-2,0,infinity)	IAEA (2009)
		Cs, Rye	2.52E-2 (0.02)	logn(6.61E-2,1.31E-1,0,infinity)	IAEA (2009)
		I, Rye	5.48E-4 (0.1)	logn(1.22E-4,2.44E-3,0,infinity)	IAEA (2009)
		Sr, Rye	9.57E-2 (0.2)	logn(1.57E-1,1.65E-1,0,infinity)	IAEA (2009)
		Cs, Spring_barley	2.52E-2 (0.02)	logn(6.61E-2,1.31E-1,0,infinity)	IAEA (2009)
		I, Spring_barley	5.48E-4 (0.1)	logn(1.22E-4,2.44E-3,0,infinity)	IAEA (2009)
		Sr, Spring_barley	9.57E-2 (0.2)	logn(1.57E-1,1.65E-1,0,infinity)	IAEA (2009)
		Cs, Spring_wheat	2.55E-2 (0.02)	logn(6.69E-2,1.32E-1,0,infinity)	IAEA (2009)
		I, Spring_wheat	5.54E-4 (0.1)	logn(1.23E-4,2.46E-3,0,infinity)	IAEA (2009)
		Sr, Spring_wheat	9.68E-2 (0.2)	logn(1.58E-1,1.67E-1,0,infinity)	IAEA (2009)
		Cs, Winter_barley	2.52E-2 (0.02)	logn(6.61E-2,1.31E-1,0,infinity)	IAEA (2009)
		I, Winter_barley	5.48E-4 (0.1)	logn(1.22E-4,2.44E-3,0,infinity)	IAEA (2009)

Parameter symbol	Parameter description	Dependencies	New default (Old default)	Distribution*/Comment	Reference
		Sr, Winter_barley	9.57E-2 (0.2)	logn(1.57E-1,1.65E-1,0,infinity)	IAEA (2009)
		Cs, Winter_wheat	2.55E-2 (0.02)	logn(6.69E-2,1.32E-1,0,infinity)	IAEA (2009)
		I, Winter_wheat	5.54E-4 (0.1)	logn(1.23E-4,2.46E-3,0,infinity)	IAEA (2009)
		Sr, Winter_wheat	9.68E-2 (0.2)	logn(1.58E-1,1.67E-1,0,infinity)	IAEA (2009)
		Cs, Berries	1.50E-3 (0.02)	logn(2.90E-3,3.30E-3,0,infinity)	IAEA (2009)
		I, Berries	1.50E-2 (0.1)		IAEA (2009)
		Sr, Berries	3.30E-2 (0.1)	logn(5.50E-2,6.9E-2,0,infinity)	IAEA (2009)
		Cs, Fruit_vegetables	1.05E-3 (0.01)	logn(3.5E-3,0.0075,0,infinity)	IAEA (2009)
		I, Fruit_vegetables	5.00E-3 (0.1)		IAEA (2009)
		Sr, Fruit_vegetables	0.018 (0.2)	logn(4.90E-2,0.09,0,infinity)	IAEA (2009)
		Cs, Root_vegetables	0.00672 (0.01)	logn(1.2E-2,0.0176,0,infinity)	IAEA (2009)
		I, Root_vegetables	0.001232 (0.1)	logn(2.08E-3,1.92E-3,0,infinity)	IAEA (2009)
		Sr, Root_vegetables	0.1152 (0.3)	logn(2.40E-1,2.24E-1,0,infinity)	IAEA (2009)
		Cs, Grass (Intensive)	0.055 (0.05)	logn(1.21E-1,1.8E-1,0,infinity)	IAEA (2009)
		I, Grass (Intensive)	8.14E-4 (0.1)	logn(9.9E-2,3.1E-2,0,infinity)	IAEA (2009)
		Sr, Grass (Intensive)	0.286 (0.5)	logn(3.74E-1,2.64E-1,0,infinity)	IAEA (2009)
		Cs, Grass (Extensive)	0.167 (1)	logn(2.42E-2,2.64E-2,0,infinity)	IAEA (2009)
		I, Grass (Extensive)	8.14E-4 (0.1)	logn(9.9E-2,3.1E-2,0,infinity)	IAEA (2009)
		Sr, Grass (Extensive)	0.286 (1)	logn(3.74E-1,2.64E-1,0,infinity)	IAEA (2009)

[1] All crops = Beet_leaves; Leafy Vegetables; Maize; Beet; Corn_cobs; Fruit; Oats; Potatoes; Rye; Spring_barley; Spring_wheat; Winter_barley; Winter_wheat.

[*] Normal = norm(mean, mean,standard deviation,truncated min,truncated max); Lognormal = Log-normal=logn(mean,standard deviation,truncated min,truncated max); Triangular = triang(min,max,mode, truncated min,truncated max); Uniform =unif(min,max, truncated min,truncated max).

Table A4.3 Animal specific parameters

Parameter symbol	**Parameter description**	**Dependencies**	**New default (Old default)**	**Distribution*/Comment**	**Reference**
S_j	*Soil intake by grazing animal, (g/g)*		0.005 (0.001)	Triang(6.4E-4,4.6E-2,5E-3,0,infinity)	See main text
TF_ik_animal product	*Transfer coefficients – Lamb, cow meat (d/kg) and milk (d/L) –*	Cs, Lamb	0.797 (0.5)	logn(8.67E-1,3.85E-1,0,infinity)	See main text
		I, Lamb	0.058 (0.01)	logn(7.78E-2,6.49E-2,0,infinity)	See main text
		Sr, Lamb	2.36E-3 (3.0E-3)	logn(2.58E-3,1.08E-3,0,infinity)	See main text
		Cs, Milk	4.60E-3 (3E-3)	logn(6.1E-3,6.3E-3,0,infinity)	IAEA (2009)
		I, Milk	5.40E-3 (3E-3)	logn(9.1E-3,7.0E-3,0,infinity)	IAEA (2009)
		Sr, Milk	1.30E-3 (2E-3)	logn(1.5E-3,8.1E-4,0,infinity)	IAEA (2009)
		Cs, Cow meat	2.20E-2 (1E-2)	logn(3.0E-2,2.3E-2,0,infinity)	IAEA (2009)
		I, Cow meat	6.70E-2 (1E-3)	logn(1.2E-2,1.5E-2,0,infinity)	IAEA (2009)
		Sr, Cow meat	1.30E-3 (3E-4)	logn(2.1e-3,2.2E-3,0,infinity)	IAEA (2009)
a_ij_Lamb	Lamb : Fractional component of biological half-life : short component a1	Cs	1 (1)	N.A.	See main text
		I	1 (1)	N.A.	See main text
		Sr	0.9 (0.2)	N.A.	See main text
	Lamb : Fractional component of biological half-life : long	Cs	0 (0)	N.A.	See main text

Parameter symbol	Parameter description	Dependencies	New default (Old default)	Distribution*/Comment	Reference
	component a2				
		I	0 (0)	N.A.	See main text
		Sr	0.1 (0.8)	N.A.	See main text
bio_half_life_Lamb	Lamb : Biological half-life :short component, (d)	Cs	16 (20)	triang(12,24,16,0,infinity)	See main text
		I	7 (100)	N.A.	See main text
		Sr	3.5 (10)	N.A.	See main text
	Lamb : Biological half-life :long component, (d)	Cs	N.A. (N.A.)	N.A.	See main text
		I	N.A. (N.A.)	N.A.	See main text
		Sr	300 (100)	N.A.	See main text
a_ij_Milk	Milk : Fractional component of biological half-life : short component a1	Cs	0.8 (0.8)	N.A.	See main text
		I	1 (1)	N.A.	See main text
		Sr	1 (0.9)	N.A.	See main text
	Milk : Fractional component of biological half-life : long component a2	Cs	0.2 (0.2)	N.A.	See main text

Parameter symbol	**Parameter description**	**Dependencies**	**New default (Old default)**	**Distribution*/Comment**	**Reference**
		I	N.A. (N.A.)	N.A.	See main text
		Sr	N.A. (0.1)	N.A.	See main text
bio_half_life_Milk	Milk : Biological half-life :short component, (d)	Cs	1.4 (1.5)	triang(0.54,2.4, 1.4,0,infinity)	See main text
		I	1 (0.7)	triang(0.6,2.1,1,0,infinity)	See main text
		Sr	2.4 (3)	triang(2,3.4,2.4,0,infinity)	See main text
	Milk : Biological half-life :long component, (d)	Cs	15 (15)	triang(5.5,40,15,0,infinity)	See main text
		I	N.A. (N.A)	N.A.	See main text
		Sr	N.A. (100)	N.A.	See main text
a_ij_Cow_Meat	Cow meat : Fractional component of biological half-life : short component a1	Cs	0.56 (1)	N.A.	See main text
		I	1 (1)	N.A.	See main text
		Sr	0.59 (0.2)	N.A.	See main text
	Cow meat : Fractional component of biological half-life : long component a2	Cs	0.44 (N.A.)	N.A.	See main text
		I	N.A. (N.A.)	N.A.	See main text

Parameter symbol	Parameter description	Dependencies	New default (Old default)	Distribution*/Comment	Reference
		Sr	0.41 (0.8)	N.A.	See main text
*bio_half_life_* Cow_Meat	Cow meat : Biological half-life :short component, (d)	Cs	9.3 (30)	triang(3,25,9.3,0,infinity)	See main text
		I	7 (100)	N.A.	See main text
		Sr	3.6 (10)	triang(3,4,3.6,0,infinity)	See main text
	Cow meat : Biological half-life :long component, (d)	Cs	53 (N.A.)	triang(30,81,53,0,infinity)	See main text
		I	N.A. (N.A)	N.A.	See main text
		Sr	325 (100)	triang(180,650,325,0,infinity)	See main text

N.A. = Not applicable

*Normal = norm (mean, mean,standard deviation,truncated min,truncated max);
Lognormal = Log-normal=logn (mean,standard deviation,truncated min,truncated max);
Triangular = triang (min,max,mode, truncated min,truncated max);
Uniform =unif (min,max, truncated min,truncated max).

Table A4.4 Soil process parameters

Parameter symbol	**Parameter description**	**Dependencies**	**New default (Old default)**	**Distribution*/Comment**	**Reference**
lambda_ai	Leaching rate of nuclide I, (d^{-1})	Cs, *Pasture_soil*	6.5E-5 (4.744E-5)	logn(1.1E-4,2.3E-4,0,infinity)	See main text
		I, *Pasture_soil*	4.744E-5 (4.744E-5)	N.A.	See main text
		Sr, *Pasture_soil*	1.2E-4 (9.489E-5)	logn(1.4E-4,8.0E-5,0,infinity)	See main text
lambda_ai_arable	Leaching rate of nuclide I, (d^{-1})	Cs, *Arable_soil*	2.6E-5 (1.898E-5)	logn(4.6E-5,9.1E-5,0,infinity)	See main text
		I, *Arable_soil*	1.7E-4 (1.898E-5)	N.A.	See main text
		Sr, *Arable_soil*	4.7E-5 (3.795E-5)	logn(5.4E-5,3.2E-5,0,infinity)	See main text
lambda_fi	Fixation rate of nuclide i	Cs	3.45E-4 (2.181E-4)	unif(1E-4,5.9E-4,0,infinity)	See main text
		I	1.898E-6 (1.898E-6)	N.A.	See main text
		Sr	9.489E-5 (9.489E-5)	N.A.	See main text
Rho_{past}	Soil density pasture	Pasture soil (Ext)	350 (1.4E3)	unif(100,600,0,infinity)	See main text
		Pasture soil (Int)	950 (1.4E3)	unif(200,1700,0,infinity)	See main text
Rho_{ara}	Soil density arable	Arable soil	1100(1.4E3)	triang(470,1700,1100,0,infinity)	See main text

*Normal = norm (mean, mean,standard deviation,truncated min,truncated max);
Lognormal = Log-normal=logn (mean,standard deviation,truncated min,truncated max);
Triangular = triang (min,max,mode, truncated min,truncated max);
Uniform =unif (min,max, truncated min,truncated max)

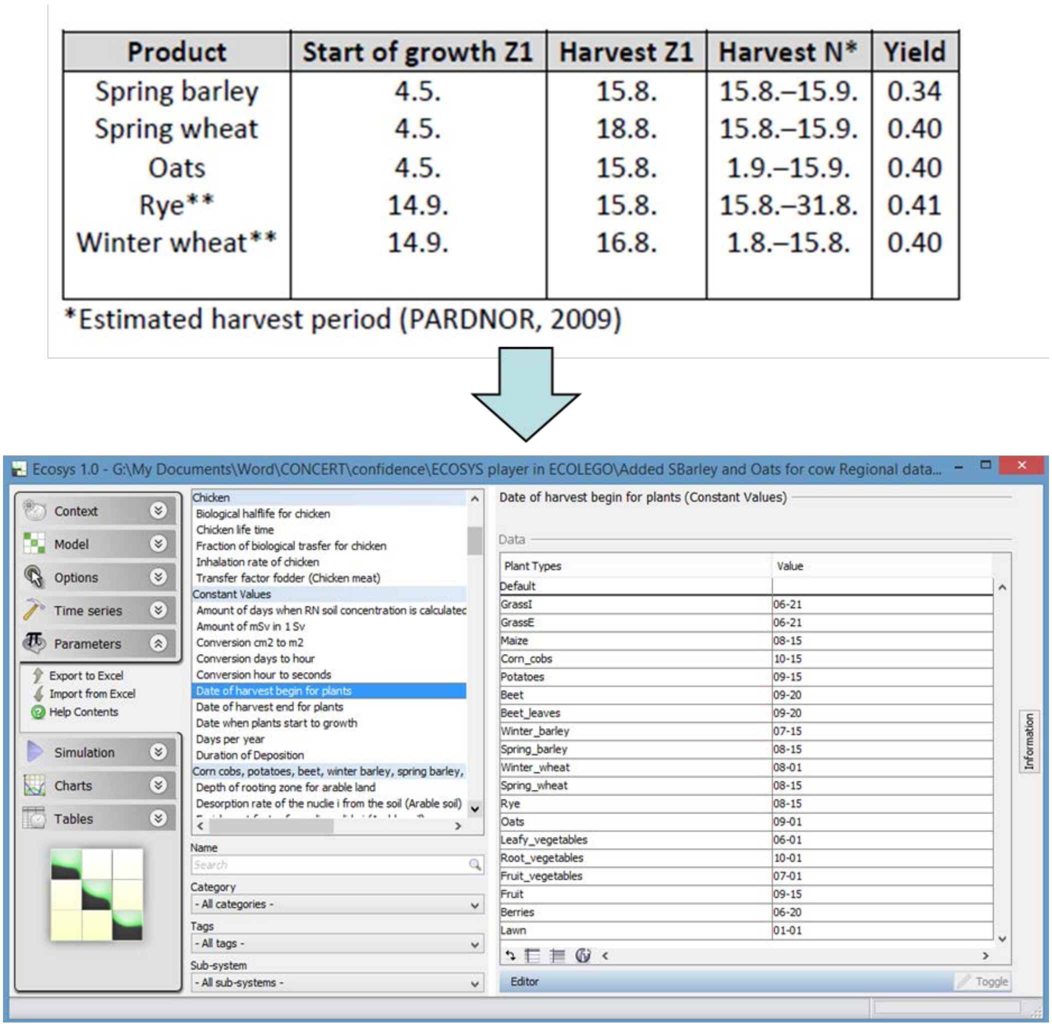
Appendix 5 – Regionalisation – parameter values

Norway

Regional data for Norway from COMET (Thørring et al., 2016a) have been used in updating FDMT-ECOSYS-87/ECOLEGO as shown below.

Cereals

The data that have been added for cereals and examples of how this information can be represented in FDMT-ECOSYS-87/ECOLEGO are provided in Figures A5.21 and A5.22.



Product	Start of growth Z1	Harvest Z1	Harvest N*	Yield
Spring barley	4.5.	15.8.	15.8.–15.9.	0.34
Spring wheat	4.5.	18.8.	15.8.–15.9.	0.40
Oats	4.5.	15.8.	1.9.–15.9.	0.40
Rye**	14.9.	15.8.	15.8.–31.8.	0.41
Winter wheat**	14.9.	16.8.	1.8.–15.8.	0.40

*Estimated harvest period (PARDNOR, 2009)

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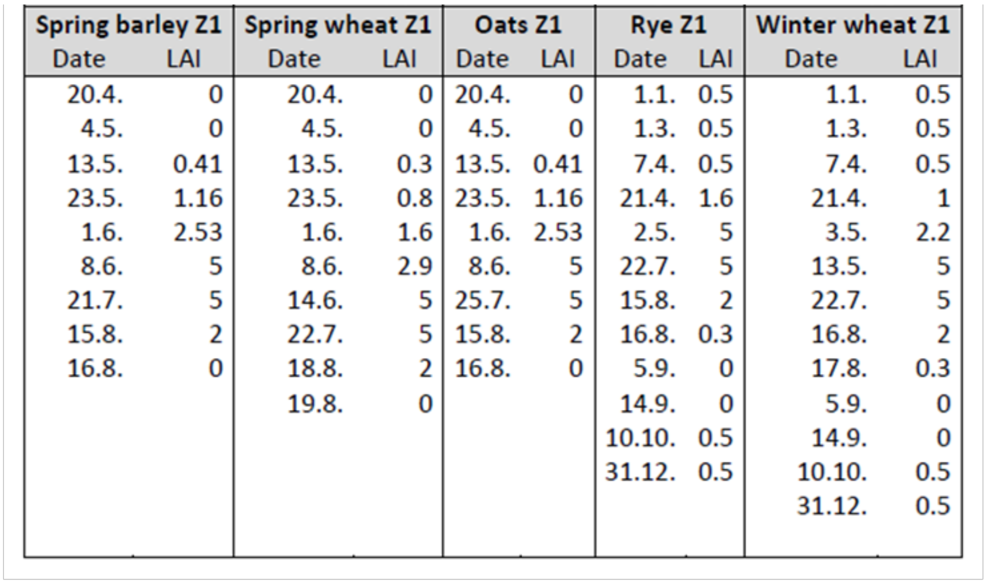
Date of harvest begin for plants (Constant Values)

Data

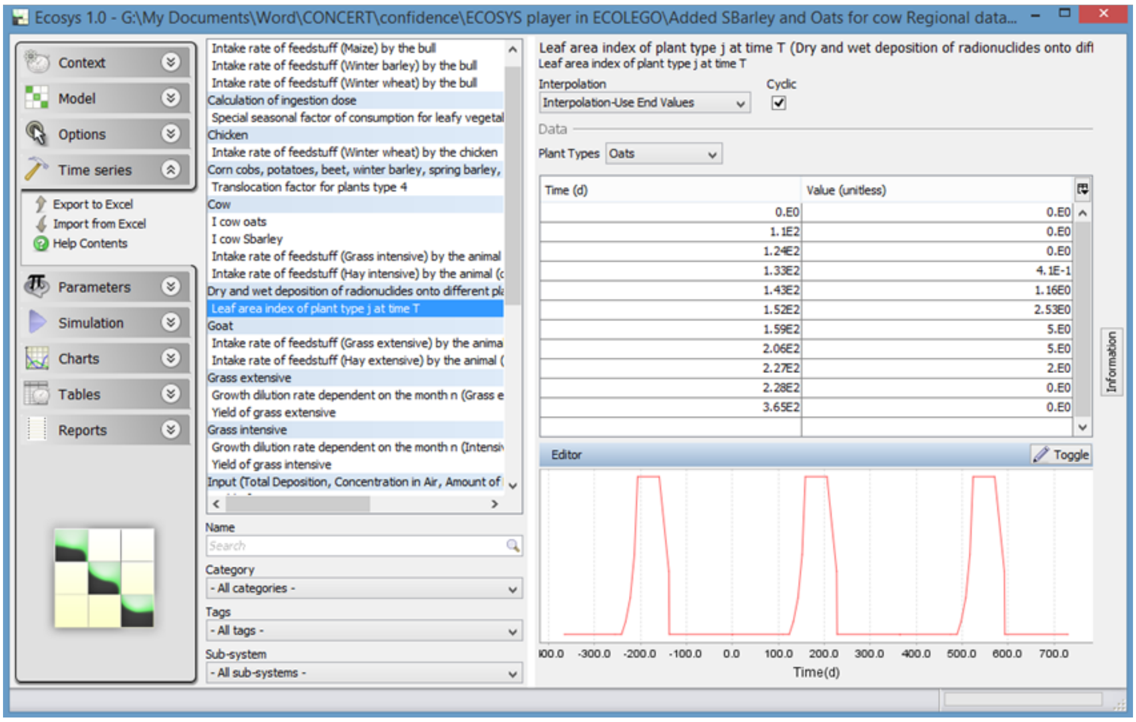
Plant Types	Value
Default	
GrassI	06-21
GrassE	06-21
Maize	08-15
Corn_cobs	10-15
Potatoes	09-15
Beet	09-20
Beet_leaves	09-20
Winter_barley	07-15
Spring_barley	08-15
Winter_wheat	08-01
Spring_wheat	08-15
Rye	08-15
Oats	09-01
Leafy_vegetables	06-01
Root_vegetables	10-01
Fruit_vegetables	07-01
Fruit	09-15
Berries	06-20
Lawn	01-01

Figure A5.21. Data for Cereals (dates for start of growth, harvest and yield) from Thørring et al., (2016a) and an example of how these data are represented in the FDMT-ECOSYS-87/ECOLEGO model ('PADNOR, 2009' is Nielsen et al. (2009)).

The values defining the start and end of harvest as defined in column 'Harvest N*' (Figure A5.21) have been used unless the value in column 'Harvest Z1' (Figure A5.21; derived from modelling the LAI) fall outside the date range. In these cases, the value in column 'Harvest Z1' has been used to either define the beginning (e.g. for Oats) or the end (e.g. for Winter wheat) of the harvest.



Spring barley Z1		Spring wheat Z1		Oats Z1		Rye Z1		Winter wheat Z1	
Date	LAI	Date	LAI	Date	LAI	Date	LAI	Date	LAI
20.4.	0	20.4.	0	20.4.	0	1.1.	0.5	1.1.	0.5
4.5.	0	4.5.	0	4.5.	0	1.3.	0.5	1.3.	0.5
13.5.	0.41	13.5.	0.3	13.5.	0.41	7.4.	0.5	7.4.	0.5
23.5.	1.16	23.5.	0.8	23.5.	1.16	21.4.	1.6	21.4.	1
1.6.	2.53	1.6.	1.6	1.6.	2.53	2.5.	5	3.5.	2.2
8.6.	5	8.6.	2.9	8.6.	5	22.7.	5	13.5.	5
21.7.	5	14.6.	5	25.7.	5	15.8.	2	22.7.	5
15.8.	2	22.7.	5	15.8.	2	16.8.	0.3	16.8.	2
16.8.	0	18.8.	2	16.8.	0	5.9.	0	17.8.	0.3
		19.8.	0			14.9.	0	5.9.	0
						10.10.	0.5	14.9.	0
						31.12.	0.5	10.10.	0.5
								31.12.	0.5



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Intake rate of feedstuff (Maize) by the bull
Intake rate of feedstuff (Winter barley) by the bull
Intake rate of feedstuff (Winter wheat) by the bull
Calculation of ingestion dose
Special seasonal factor of consumption for leafy vegetal
Chicken
Intake rate of feedstuff (Winter wheat) by the chicken
Corn cobs, potatoes, beet, winter barley, spring barley,
Translocation factor for plants type 4
Cow
I cow oats
I cow Sbarley
Intake rate of feedstuff (Grass intensive) by the animal
Intake rate of feedstuff (Hay intensive) by the animal (c
Dry and wet deposition of radionuclides onto different pla
Leaf area index of plant type j at time T
Goat
Intake rate of feedstuff (Grass extensive) by the anima
Intake rate of feedstuff (Hay extensive) by the animal (
Grass extensive
Growth dilution rate dependent on the month n (Grass e
Yield of grass extensive
Grass intensive
Growth dilution rate dependent on the month n (Intensi
Yield of grass intensive
Input (Total Deposition, Concentration in Air, Amount of

Name: Search
Category: - All categories -
Tags: - All tags -
Sub-system: - All sub-systems -

Leaf area index of plant type j at time T (Dry and wet deposition of radionuclides onto difi
Leaf area index of plant type j at time T

Interpolation: Interpolation-Use End Values
Cyclic ☑

Data
Plant Types: Oats

Time (d)	Value (unitless)
0.E0	0.E0
1.1E2	0.E0
1.24E2	0.E0
1.33E2	4.1E-1
1.43E2	1.16E0
1.52E2	2.53E0
1.59E2	5.E0
2.06E2	5.E0
2.27E2	2.E0
2.28E2	0.E0
3.65E2	0.E0

Figures A5.22 Data (LAI versus time) for Cereals from Thørring et al. (2016a) and an example (LAI for oats) of how these data are represented in the FDMT-ECOSYS-87/ECOLEGO model.

Vegetables, fruits and berries

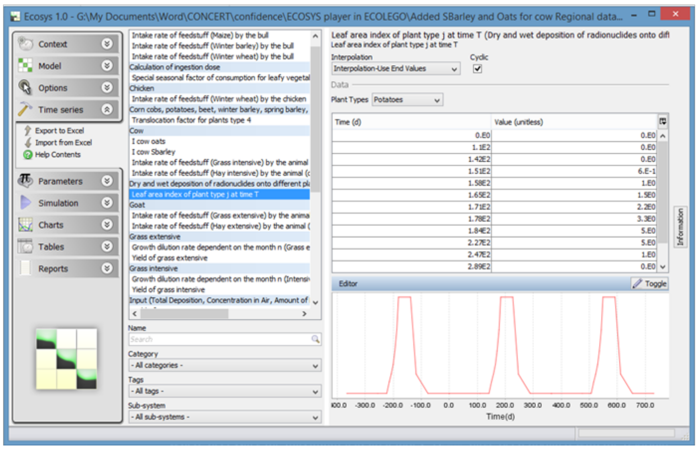
Data that have been added for vegetables, fruits and berries and examples of how this information can be represented in FDMT-ECOSYS-87/ECOLEGO are provided in Figure A5.23.

Product	Start of growth Z1	Harvest N	Yield
Potatoes	22.5.	15.9.–15.10	2.5
Leafy vegetables[a)]	10.4.	1.6. –31.10.	2.4
Root vegetables[b)]	1.6.	1.10.–31.10.	2.4
Fruit vegetables[c)]	8.5.	1.7.–15.8.	2.8
Fruit[d)]	1.5.	15.9.–15.10.	0.51
Berries[e)]	1.4.	20.6.–15.8.	0.35

[a)] Various cabbage and lettuce plus leek and Brussels sprout (2010–2014, Statistics Norway).
[b)] Swede, carrot, beetroot, onion, celeriac and turnip (2010–2014, Statistics Norway)
[c)] Gherkin (2010–2014, Statistics Norway)

Potatoes Z1		Leafy v. Z1*		Root v. Z1		Fruit v. Z1		Fruit Z1*		Berries Z1*	
Date	LAI	Date	LAI	Date	LAI	Date	LAI	Date	LAI	Date	LAI
20.4.	0	10.4.	0	20.4.	0	20.4.	0	1.5.	0	1.4.	0
22.5.	0	1.5.	1	22.5.	0	8.5.	0	15.5.	0.5	10.4.	1
31.5.	0.6	1.6.	5	1.6.	0	1.6.	0.2	1.6.	4	1.5.	3
7.6.	1	15.9.	4	7.6.	0.1	7.6.	1.1	15.7.	5	20.6.	5
14.6.	1.5	31.10.	2.5	14.6.	0.3	14.6.	3.9	1.10.	4	15.8.	5
20.6.	2.2	15.11.	0	20.6.	0.5	15.6.	5	31.10.	0	15.9.	0
27.6.	3.3			27.6.	1.2	1.7.	5				
3.7.	5			10.7.	2	5.8.	2.5				
15.8.	5			3.8.	5	1.9.	0				
4.9.	1			01.11.	0						
16.10.	0										

*Danish data used (PARDNOR, 2009)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Intake rate of feedstuff (Maize) by the bull
Intake rate of feedstuff (Winter barley) by the bull
Intake rate of feedstuff (Winter wheat) by the bull
Calculation of ingestion dose
Special seasonal factor of consumption for leafy vegetal
Chicken
Intake rate of feedstuff (Winter wheat) by the chicken
Corn cobs, potatoes, beet, winter barley, spring barley,
Translocation factor for plants type 4
Cow
I cow oats
I cow Sbarley
Intake rate of feedstuff (Grass intensive) by the animal
Intake rate of feedstuff (Hay intensive) by the animal (c
Dry and wet deposition of radionuclides onto different pl
Leaf area index of plant type j at time T
Goat
Intake rate of feedstuff (Grass extensive) by the anima
Intake rate of feedstuff (Hay extensive) by the animal (
Grass extensive
Growth dilution rate dependent on the month n (Grass e
Yield of grass extensive
Grass intensive
Growth dilution rate dependent on the month n (Intensi
Yield of grass intensive
Input (Total Deposition, Concentration in Air, Amount of

Name: Search
Category: - All categories -
Tags: - All tags -
Sub-system: - All sub-systems -

Leaf area index of plant type j at time T (Dry and wet deposition of radionuclides onto dif
Leaf area index of plant type j at time T
Interpolation: Interpolation-Use End Values
Cyclic ☑
Data
Plant Types: Potatoes

Time (d)	Value (unitless)
0.E0	0.E0
1.1E2	0.E0
1.42E2	0.E0
1.51E2	6.E-1
1.58E2	1.E0
1.65E2	1.5E0
1.71E2	2.2E0
1.78E2	3.3E0
1.84E2	5.E0
2.27E2	5.E0
2.47E2	1.E0
2.89E2	0.E0

Figure A5.23 Data for vegetables, fruits and berries (dates for start of growth, harvest and yield, LAI versus time) from Thørring et al. (2016a) and an example (LAI for potatoes) of how these data are represented in the FDMT-ECOSYS-87/ECOLEGO model.

Where necessary the maximum LAI, $B_{j,max}$, have been updated with the regional values.

Most of the data in are entered as “time-points” and, as such, provide no option to enter the data as distributions. However, the possibility exists to enter the ‘Yield at harvest’ as a distribution.

Grass

For the purpose of demonstration the data for Zone 2 have been used in the FDMT-ECOSYS-87/ECOLEGO system. Changing the grass (extensive or intensive) parameters was more challenging. The default parameters for the ECOLEGO ECOSYS-87 are presented in Table A5.9.

Table A5.9 ECOLEGO default parameters for grass.

Parameter symbol	**Fodder**	**Description**	**Date**
$\text{Date}_{\text{start,growth}}$	Grass	Start of growing season for grass	15.03
$\text{Date}_{\text{Harvest,Starts,GrassE}}$	Grass	Begin of feeding fresh forage (Mean, Table 18 in Müller & Pröhl (1993).	21.04*
$\text{Date}_{\text{Harvest,End,GrassE}}$	Grass	End of feeding fresh forage. Full hay and silage feeding (Mean, Table 18 in Müller & Pröhl (1993).	10.11
$t_{\text{harvest,begins}}$	Hay/silage	Start of preparing hay and silage (Mean, Table 18 in Müller & Pröhl (1993).	16.05
$t_{\text{harvest,middle}}$	Hay/silage	Date of the end of first harvest period for hay. Derived from start of preparing hay (16.05 above) and Full hay/silage feeding (15.11 : Max, Table 18 in Müller & Pröhl (1993). Total Period = 6 months; 1st time point = after 2 months	15.07
$t_{\text{harvest,ends}}$	Hay/silage	Date of the end of harvest for hay. Derived from start of preparing hay (16.05 above) and Full hay/silage feeding (15.11 : Max, Table 18 in Müller & Pröhl (1993). Total Period = 6 months; 2nd time point = after 4 months	15.09

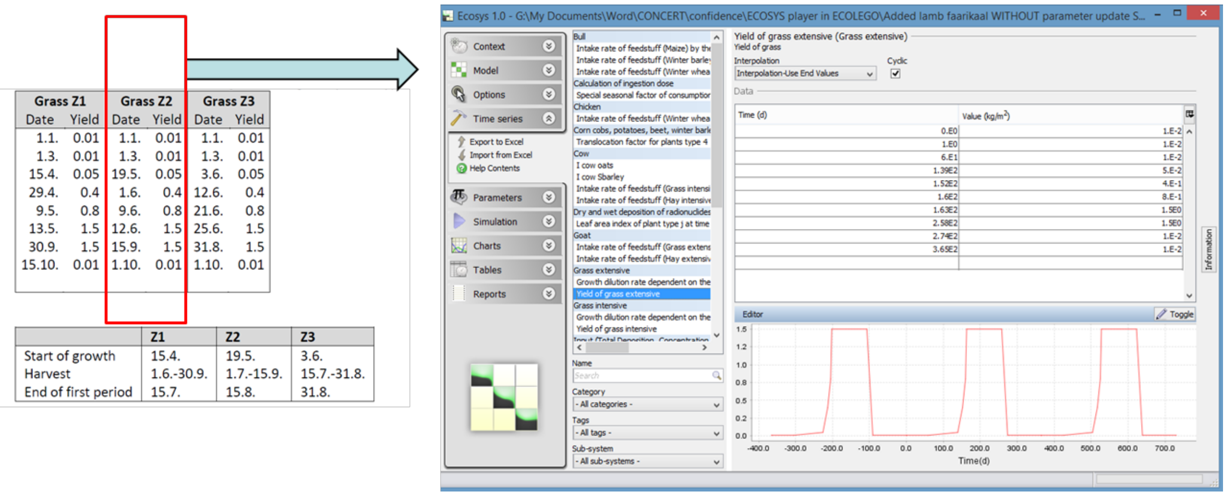
*Denmark

The new ECOLEGO default parameters for Regional area Zone 2 (Z2) in Norway are provided below (Table A5.10). From Thørring et al. (2016a) a harvest period defining the FDMT default is given as 1st May to 31st October. This corresponds to the period defined by 'Begin of feeding fresh forage' (Max, Table 18 in Müller & Pröhl (1993) and 'Begin of feeding hay and silage' (Max, Table 18 in Müller & Pröhl (1993). The Regional default value provided by Thørring et al. 2016a for Z2 in Norway for the harvest period is 1st July to 15th September. The start of the harvest has, therefore, been shifted back in time so that it falls 2 months later than the FDMT default and the end of the harvest shifted to occur 1.5 months earlier than the FDMT default.

Table A5.10 ECOLEGO default parameter values for Zone 2, Norway.

Parameter symbol	Fodder	Description	Date
$\mathrm{Date}_{\mathrm{start,growth}}$	Grass	Start of growing season for grass (for Z2 from Thørring et al., 2016a)	19.05
$\mathrm{Date}_{\mathrm{Harvest,Starts,GrassE}}$	Grass	Begin of feeding fresh forage. Table 3.17 (for Z2 from Thørring et al., 2016a) provides this date for when cows start to eat grass.	01.06
$\mathrm{Date}_{\mathrm{Harvest,End,GrassE}}$	Grass	End of feeding fresh forage. Table 3.17 (for Z2 from Thørring et al., 2016a) provides this date for when cows end eating grass.	14.09
$t_{\mathrm{harvest,begins}}$	Hay/silage	Start of preparing hay and silage. Using data in Müller & Pröhl (1993), this occurs 0.5 months after the start of grass harvest (01.05). This value of 0.5 months has been added to the start of the harvest for Z2, i.e. 01 July, from Thørring et al., 2016a).	15.07
$t_{\mathrm{harvest,middle}}$	Hay/silage	Date of the end of first harvest period for hay (for Z2 from Thørring et al., 2016a).	15.08
$t_{\mathrm{harvest,ends}}$	Hay/silage	Date of the end of harvest period for hay (for Z2 from Thørring et al., 2016a).	15.09

Data for grass yields (grass intensive and extensive) have also been incorporated (Figure A5.24).



Grass Z1		Grass Z2		Grass Z3	
Date	Yield	Date	Yield	Date	Yield
1.1.	0.01	1.1.	0.01	1.1.	0.01
1.3.	0.01	1.3.	0.01	1.3.	0.01
15.4.	0.05	19.5.	0.05	3.6.	0.05
29.4.	0.4	1.6.	0.4	12.6.	0.4
9.5.	0.8	9.6.	0.8	21.6.	0.8
13.5.	1.5	12.6.	1.5	25.6.	1.5
30.9.	1.5	15.9.	1.5	31.8.	1.5
15.10.	0.01	1.10.	0.01	1.10.	0.01

	Z1	Z2	Z3
Start of growth	15.4.	19.5.	3.6.
Harvest	1.6.-30.9.	1.7.-15.9.	15.7.-31.8.
End of first period	15.7.	15.8.	31.8.

Ecosys 1.0 - G:\My Documents\Word\CONCERT\confidence\ECOSYS player in ECOLEGO\Added lamb faarikaal WITHOUT parameter update S...

Yield of grass extensive (Grass extensive)
Yield of grass

Interpolation: Interpolation-Use End Values
Cyclic: ☑

Time (d)	Value (kg/m²)
0.E0	1.E-2
1.E0	1.E-2
6.E1	1.E-2
1.39E2	5.E-2
1.52E2	4.E-1
1.6E2	8.E-1
1.63E2	1.5E0
2.58E2	1.5E0
2.74E2	1.E-2
3.65E2	1.E-2

Figure A5.24 Data for grass (dates for start of growth, harvest and yield, LAI versus time) from Thørring et al. (2016a) and an example (LAI grass Z2) of how these data are represented in the FDMT-ECOSYS-87/ECOLEGO model.

Feedstuffs for animals

The feeding regime data for Lactating cow and Lamb for Z2 entered into the FDMT-ECOSYS-87/ECOLEGO system are presented in Table A5.11.

Table A5.11 Feedstuffs for animals (kg fresh mass per day) (Norway; Zone 2) from Thørring et al. (2016a).

Animal	Date	Grass I	Grass E	Hay I	S. barley	W. wheat	Oats
Lactating cow Z2	1.1.			12	3.1		1.2
	1.6.	50			2.0		0.78
	14.9.	50			2.0		0.78
	15.9.			12	3.1		1.2
	31.12.			12	3.1		1.2
Lamb Z2	1.6.		2.5				
	15.8.		3.5				
	15.9.		5.0				

An additional date has been added to the information provided in Thørring et al. (2016a) for Lactating cows to account for the transition from winter to summer forage (Table A5.12).

Table A5.12. ECOLEGO default parameters for Norwegian feedstuffs in Z2 - Milking Cow (kg FM consumed per day).

Date	Julian day	Grass I	Hay I	S. Barley	Oats	Comment	
01.jan	1	0	12	3,1	1,2		
25.mai	145	0	12	3,1	1,2	1 week transition period	
01.jun	152	50	0	2	0,78		
14.sep	257	50	0	2	0,78		
15.sep	258	0	12	3,1	1,2		
31.des	365	0	12	3,1	1,2		

For lamb, additional time points are also required to account for the transition period for when lamb are released onto, and brought in from, pasture (Table A5.13). Based on knowledge of Norwegian framing practice, this transition period was assumed to be short (1 day).

Table A5.13. ECOLEGO default parameters for Norwegian feedstuffs Z2 – Lamb (kg FM consumed per day).

Date	Julian day	Grass E
01.jan	0	0
31.mai	151	0
01.jun	152	2,5
15.aug	227	3,5
15.sep	258	5
16.sep	259	0
31.des	365	0

Spain

Parameters as used for Spain in the ECOLEGO implementation of FDMT are presented in Tables A5.14 – A5.17.

Table A5.14. Yield data for Spain (taken from Thørring et al. (2016)) and LAI values as used in the ECOLEGO implementation of FDMT.

Julian Day	Yield winter wheat (kg/m2)	LAI winter wheat (kg/m2)	Yield winter wheat (kg/m2)	LAI winter wheat (kg/m2)
1	0	0.00	0	0.00
31	0.01	0.04	0.01	0.04
59	0.02	0.08	0.1	0.38
90	0.05	0.20	0.29	1.01
120	0.17	0.63	0.36	1.21
151	0.45	1.45	0.34	1.15
181	0.70	2.01	0	0.00
212	0.69	1.99	0	0.00
243	0.63	1.87	0	0.00
273	0.47	1.50	0	0.00
304	0.20	0.73	0.01	0.04
334	0.04	0.16	0.1	0.38
365	0	0.00	0.04	0.16

Table A5.15. LAI time series of LAI values for Spain as derived for 'Grass extensive' and 'Grass intensive'.

Day	Yield Grass extensive (kg/m2)	LAI Grass extensive	Yield Grass intensive (kg/m2)	LAI Grass intensive
1	0	0.00	0	0.00
31	0.01	0.04	0.01	0.04
59	0.02	0.08	0.1	0.38
90	0.05	0.20	0.29	1.01
120	0.17	0.63	0.36	1.21
151	0.45	1.45	0.34	1.15
181	0.70	2.01	0	0.00
212	0.69	1.99	0	0.00
243	0.63	1.87	0	0.00
273	0.47	1.50	0	0.00
304	0.20	0.73	0.01	0.04
334	0.04	0.16	0.1	0.38
365	0	0.00	0.04	0.16

Table A5.16. Harvest dates for main Spanish crop considered and grass (MAPAMA, 1993).

Crops	Start of Growth	Start of Harvest	End of Harvest
Winter Wheat	1.11 (day 305)	17.06 (day 168 next year)	
Spring Wheat	1.11 (day 305)	18.05 (day 138 next year)	
Leafy Vegetables	1.07 (day 182)	9.11 (day 313)	
Grass Extensive	1.01 (day 1)	1.03 (day 60)	31.12 (day 365)
Grass Intensive	1 .11 (day 60)	1.04 (day 91)	31.06 (day 154)

Table A5.17. Yield data for Spain as implemented in ECOLEGO (Thørring et al. 2016).

Crops Types	Yield (kg/m^2)
Winter Wheat	0.27
Spring Wheat	0.38
Winter Barley	0.28
Spring barley	0.37
Leafy Vegetables	2.39
Potatoes	2.83
Oats	0.22

Table A5.18. Spanish data for cow milk diets.

Day	Grass Intensive Intake Feedstuffs (kg fresh weight per day)	Hay Intensive Intake Feedstuffs (kg fresh weight per day)
1	0	21
31	0	21
59	3	20
90	8	19
120	31	14
151	75	3
181	75	3
212	75	3
243	75	3
273	63	6
304	37	12
334	7	19
365	0	21

Appendix 6 – Probabilistic model runs: wet deposition scenarios

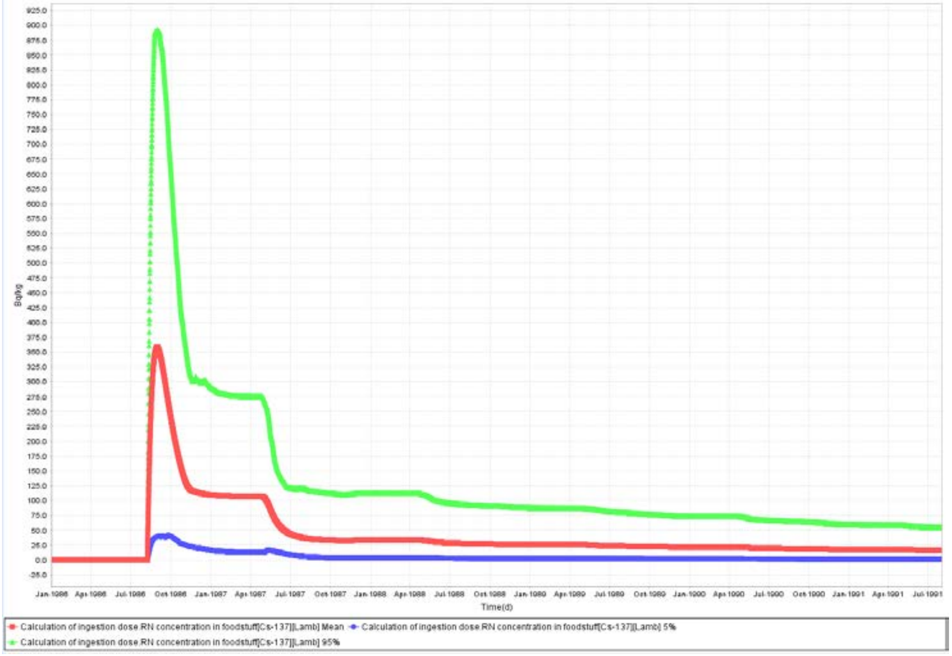


Figure A6.1 Probabilistic simulation of activity concentration of Cs-137 in lamb for wet deposition scenario. 5th percentile (blue), mean (red) and 95th percentile (green).

Table A6.1 Statistics for activity concentration of Cs-137 in lamb for wet deposition scenario at day 248 (35 days after initial deposition).

Statistics	**Lamb, Cs-137 (Bq/kg) Wet deposition (248 d after initial deposition)**
Mean	349
Std. Deviation	288
5%	40
Median	280
95%	888

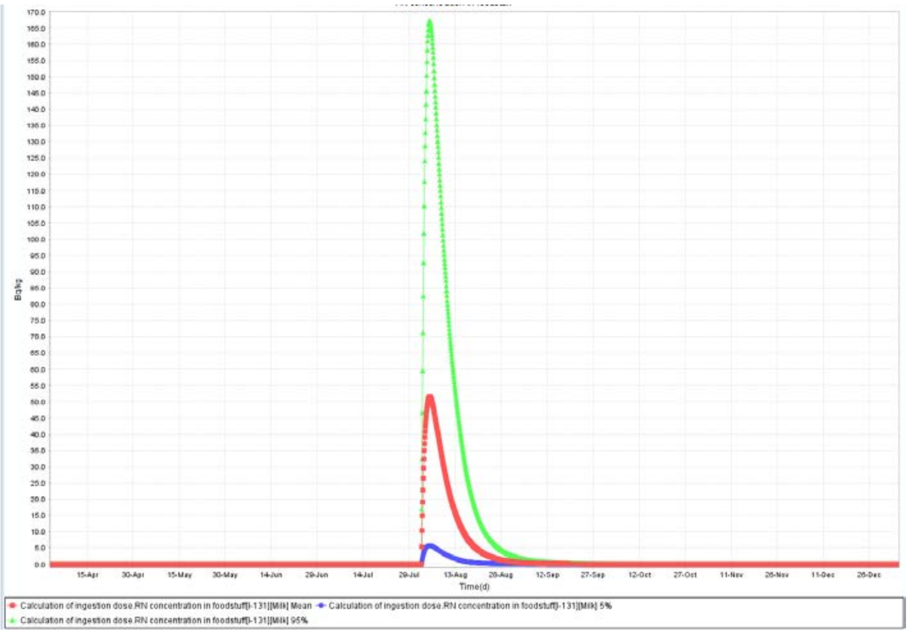


Figure A6.2 Probabilistic simulation of activity concentration of I-131 in cow milk for wet deposition scenario. 5th percentile (blue), mean (red) and 95th percentile (green).

Table A6.2 Statistics for activity concentration of I-131 in cow milk for wet deposition scenario at day 216 (3 days after initial deposition).

Statistics	**Cow Milk, I-131 (Bq/kg)** **Wet deposition (216 d after initial deposition)**
Mean	5
Std. Deviation	33
5%	49
Median	55
95%	148

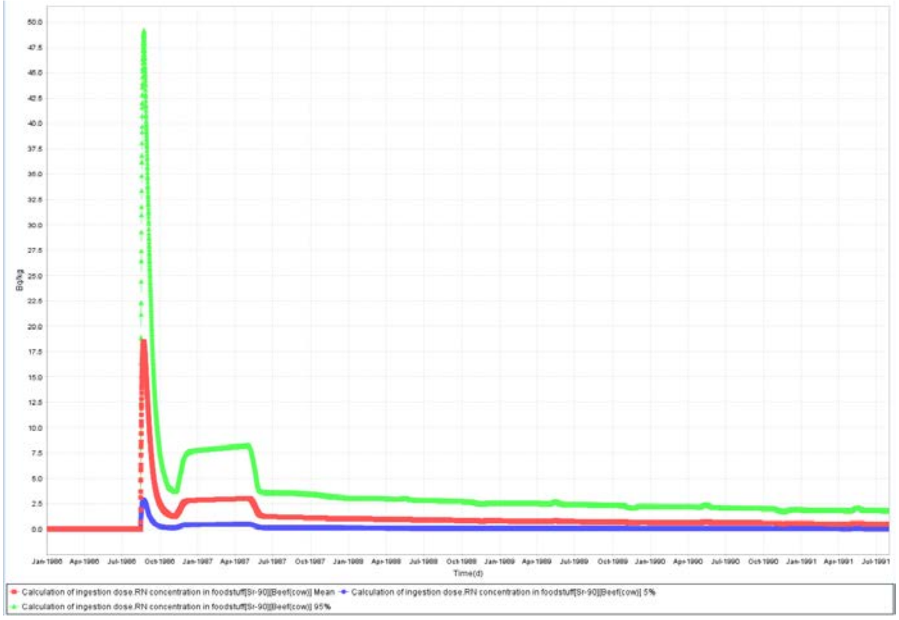


Figure A6.3 Probabilistic simulation of activity concentration of Sr-90 in beef (cow) for wet deposition scenario. 5th percentile (blue), mean (red) and 95th percentile (green).

Table 6.3 Statistics for activity concentration of Sr-90 in beef (cow) for wet deposition scenario at day 235 (22 days after initial deposition).

Statistics	**Beef (cow), Sr-90 (Bq/kg)** **Wet deposition (235 d after initial deposition)**
Mean	18
Std. Deviation	19
5%	3
Median	13
95%	49

Appendix 7 – Sensitivity analyses: Additional results

I-131 Leafy vegetables

Table A7.1 Statistics from probabilistic simulations in ECOLEGO – I-131 leafy vegetables.

Parameter	**1 day**	**1 week**	**2 weeks**	**1 month**	**2 months**	**1 year**	**10 years**	**25 years**
Median	0,0E+00	3,7E+01	9,8E+00	3,5E-01	7,9E-05	2,9E-16		
Std. dev.	0,0E+00	2,1E+01	6,9E+00	4,4E-01	1,2E-04	4,5E-16		
5%	0,0E+00	6,5E+00	1,6E+00	3,7E-02	1,9E-05	7,0E-17		
95%	0,0E+00	7,5E+01	2,4E+01	1,4E+00	2,8E-04	1,0E-15		
R2		0,96	0,90	0,72	0,76	0,74		
R2 ranked		0,97	0,93	0,92	0,88	0,87		

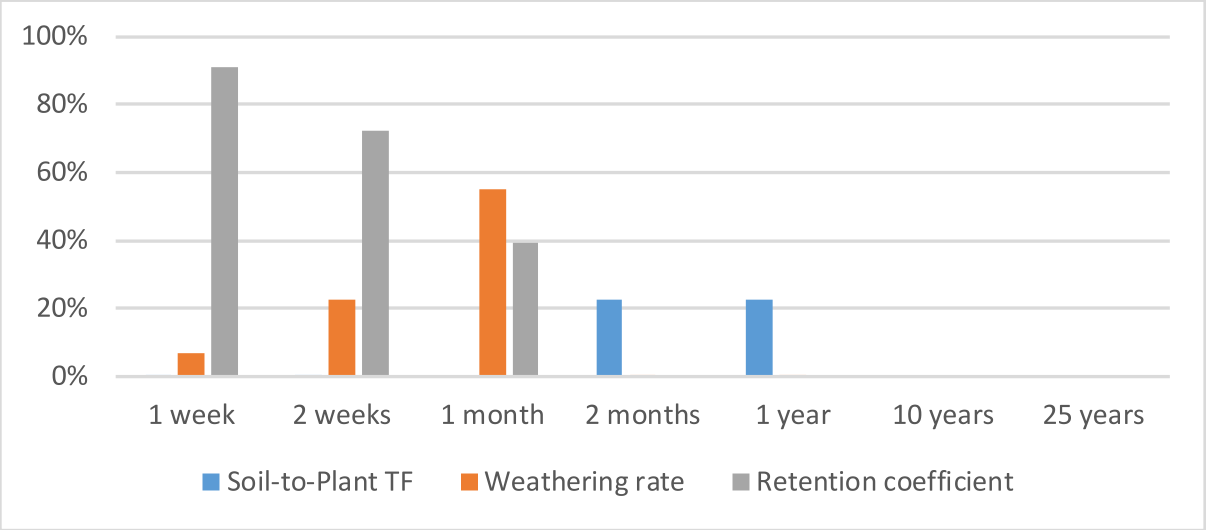


Figure A7.1 Effective Algorithm for Global Sensitivity Indices (EASI) as a function of time – I-131 Leafy vegetables.

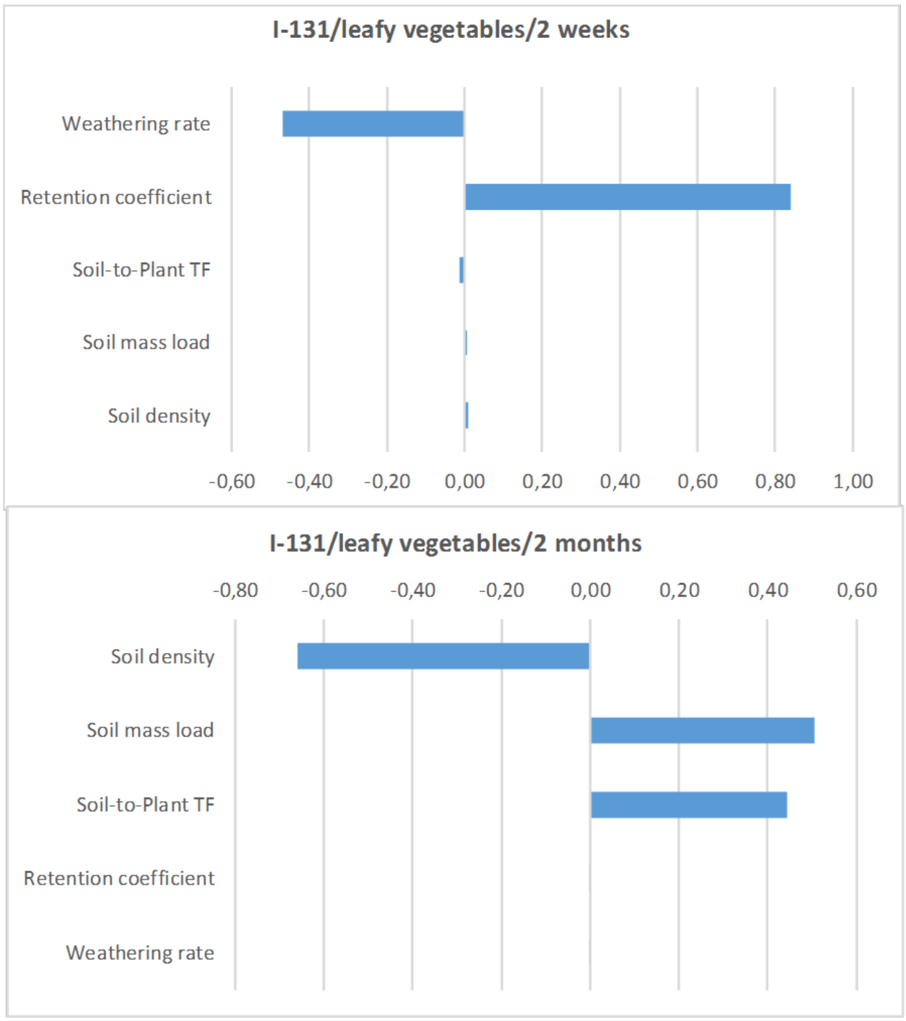


Figure A7.2 Spearman rank correlation coefficients between ECOLEGO parameters and output, for various time points; I-131 leafy vegetables.

I-131 – Lamb

Table A7.2 Statistics from ECOLEGO probabilistic simulations – I-131 Lamb.

Parameter	**1 day**	**1 week**	**2 weeks**	**1 month**	**2 months**	**1 year**	**10 years**	**25 years**
Median	0,0E+00	0,0E+00	4,6E+00	8,6E-01	2,2E-02	2,5E-14		
Std. dev.	0,0E+00	0,0E+00	8,0E+00	1,7E+00	4,3E-02	4,5E-14		
5%	0,0E+00	0,0E+00	6,2E-01	1,3E-01	4,5E-03	6,0E-15		
95%	0,0E+00	0,0E+00	2,2E+01	4,2E+00	1,0E-01	1,1E-13		
R2			0,82	0,78	0,72	0,72		
R2 ranked			0,93	0,93	0,93	0,95		

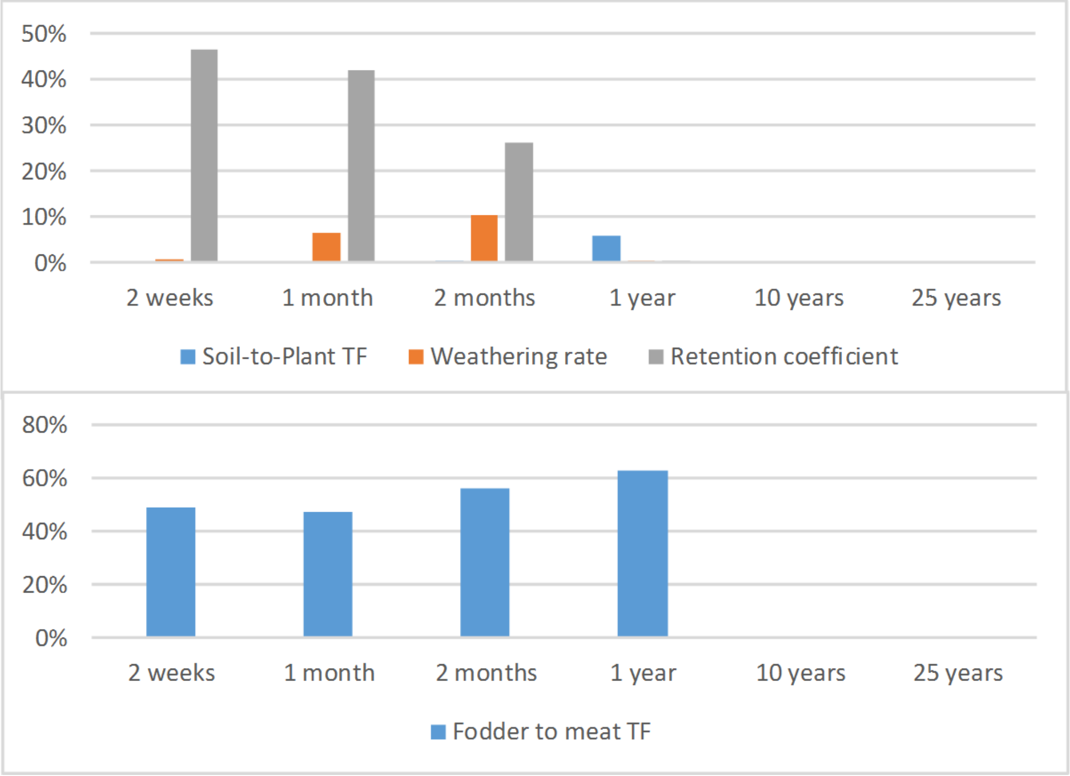


Figure A7.3 Effective Algorithm for Global Sensitivity Indices (EASI) as function of time – I-131 Lamb

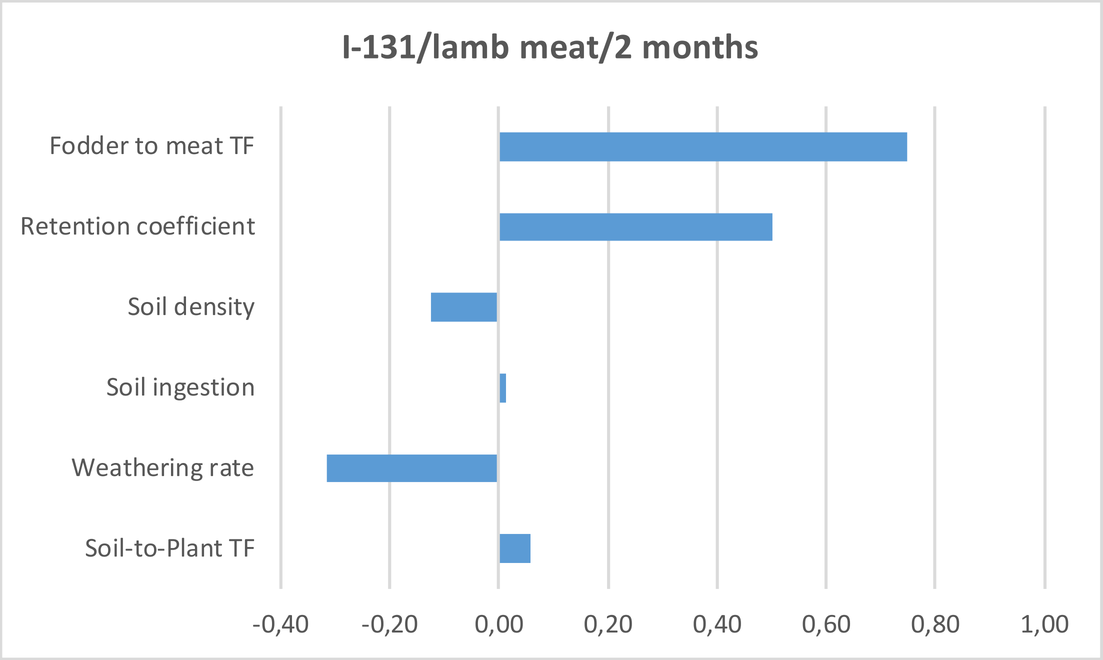


Figure A7.4 Spearman rank correlation coefficients between ECOLEGO parameters and output at 2 months; I-131 lamb.

Sr-90 Leafy vegetables

Table A7.3 Statistics from ECOLEGO probabilistic simulations – Sr-90 Leafy vegetables.

Parameter	**1 day**	**1 week**	**2 weeks**	**1 month**	**2 months**	**1 year**	**10 years**	**25 years**
Median	0,0E+00	1,9E+02	1,1E+02	2,6E+01	5,8E-01	5,5E-01	2,7E-01	8,3E-02
Std. dev.	0,0E+00	6,5E+01	4,5E+01	1,7E+01	1,1E+00	1,0E+00	5,2E-01	1,7E-01
5%	0,0E+00	4,3E+01	2,4E+01	4,7E+00	1,2E-01	1,2E-01	5,5E-02	1,6E-02
95%	0,0E+00	2,6E+02	1,8E+02	5,9E+01	2,8E+00	2,6E+00	1,3E+00	4,3E-01
R2		0,81	0,82	0,79	0,70	0,69	0,69	0,66
R2 ranked		0,95	0,90	0,88	0,96	0,95	0,95	0,94

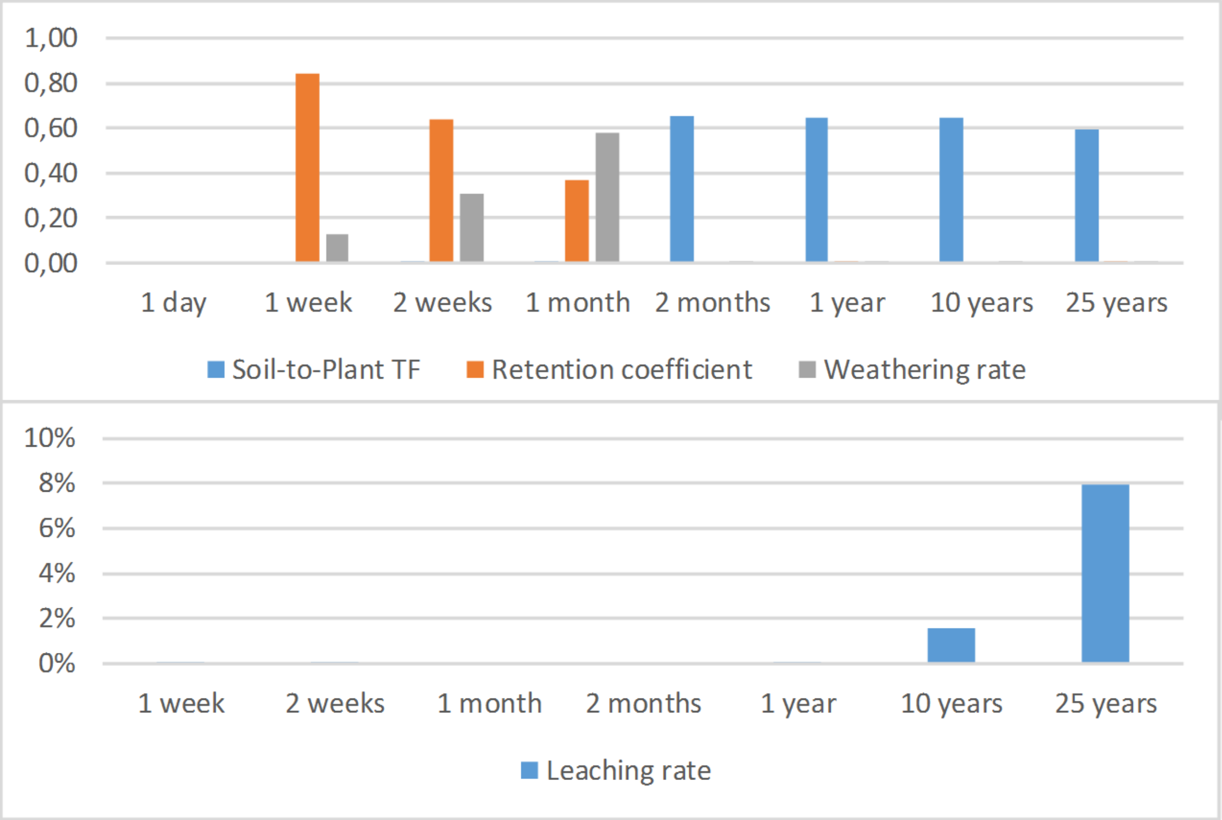
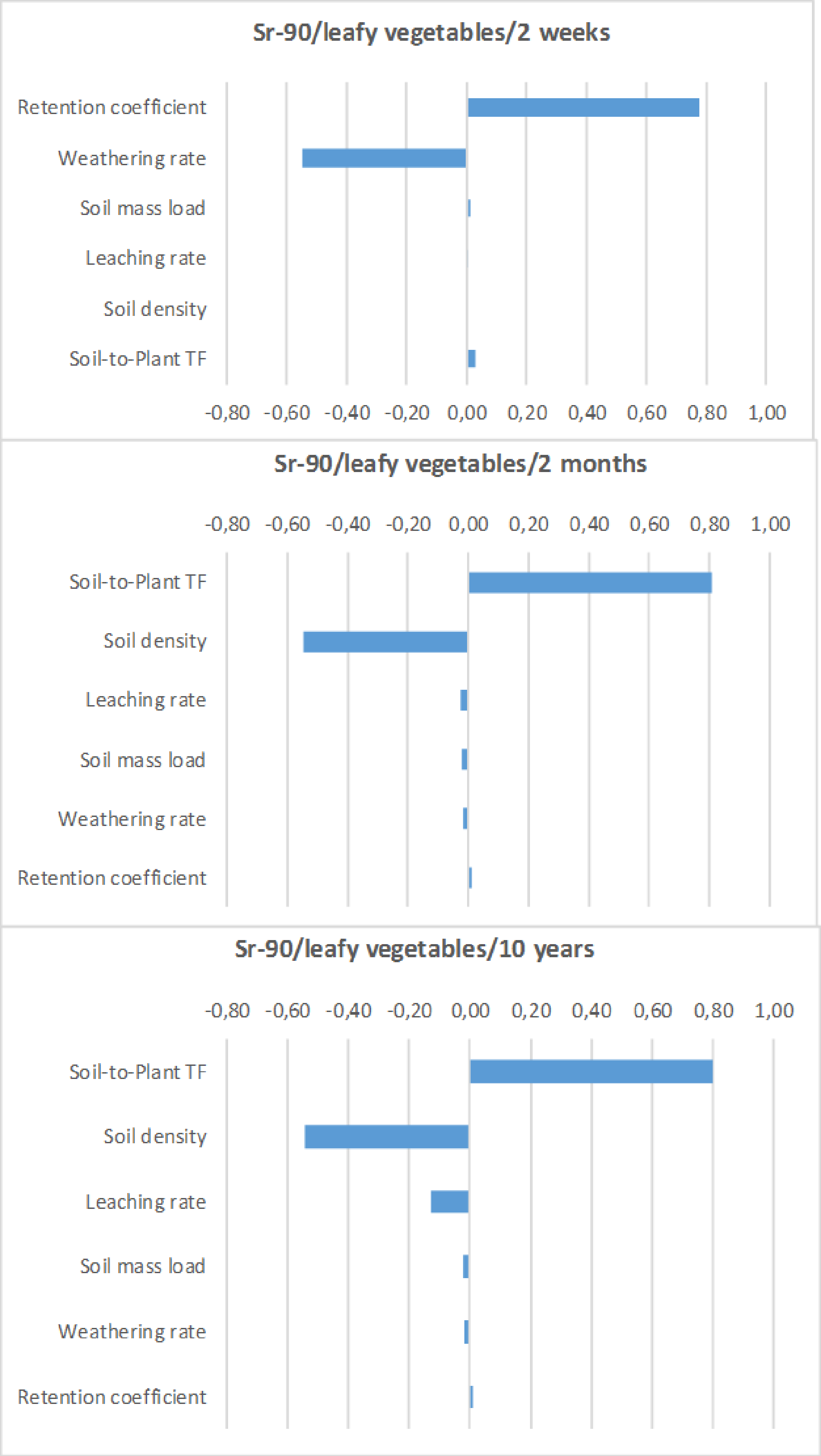


Figure A7.5 Effective Algorithm for Global Sensitivity Indices (EASI) as a function of time – Sr-90 Leafy vegetables.



Sr-90/leafy vegetables/2 weeks

Sr-90/leafy vegetables/2 months

Sr-90/leafy vegetables/10 years

Figure A7.6 Spearman rank correlation coefficients between ECOLEGO parameters and output, for various time points; Sr-90 leafy vegetables.

Sr-90 – Lamb

Table A7. 4 Statistics from ECOLEGO probabilistic simulations – Sr-90 Lamb

Parameter	**1 day**	**1 week**	**2 weeks**	**1 month**	**2 months**	**1 year**	**10 years**	**25 years**
Median	0,0E+00	0,0E+00	2,6E+00	1,5E+00	4,2E-01	1,1E-01	3,9E-02	7,9E-03
Std. dev.	0,0E+00	0,0E+00	1,7E+00	1,2E+00	4,4E-01	1,7E-01	6,8E-02	1,8E-02
5%	0,0E+00	0,0E+00	4,5E-01	2,7E-01	1,0E-01	3,0E-02	8,6E-03	1,1E-03
95%	0,0E+00	0,0E+00	6,0E+00	3,8E+00	1,4E+00	4,3E-01	1,7E-01	4,1E-02
R2			0,86	0,83	0,71	0,68	0,66	0,57
R2 ranked			0,90	0,87	0,87	0,93	0,92	0,91

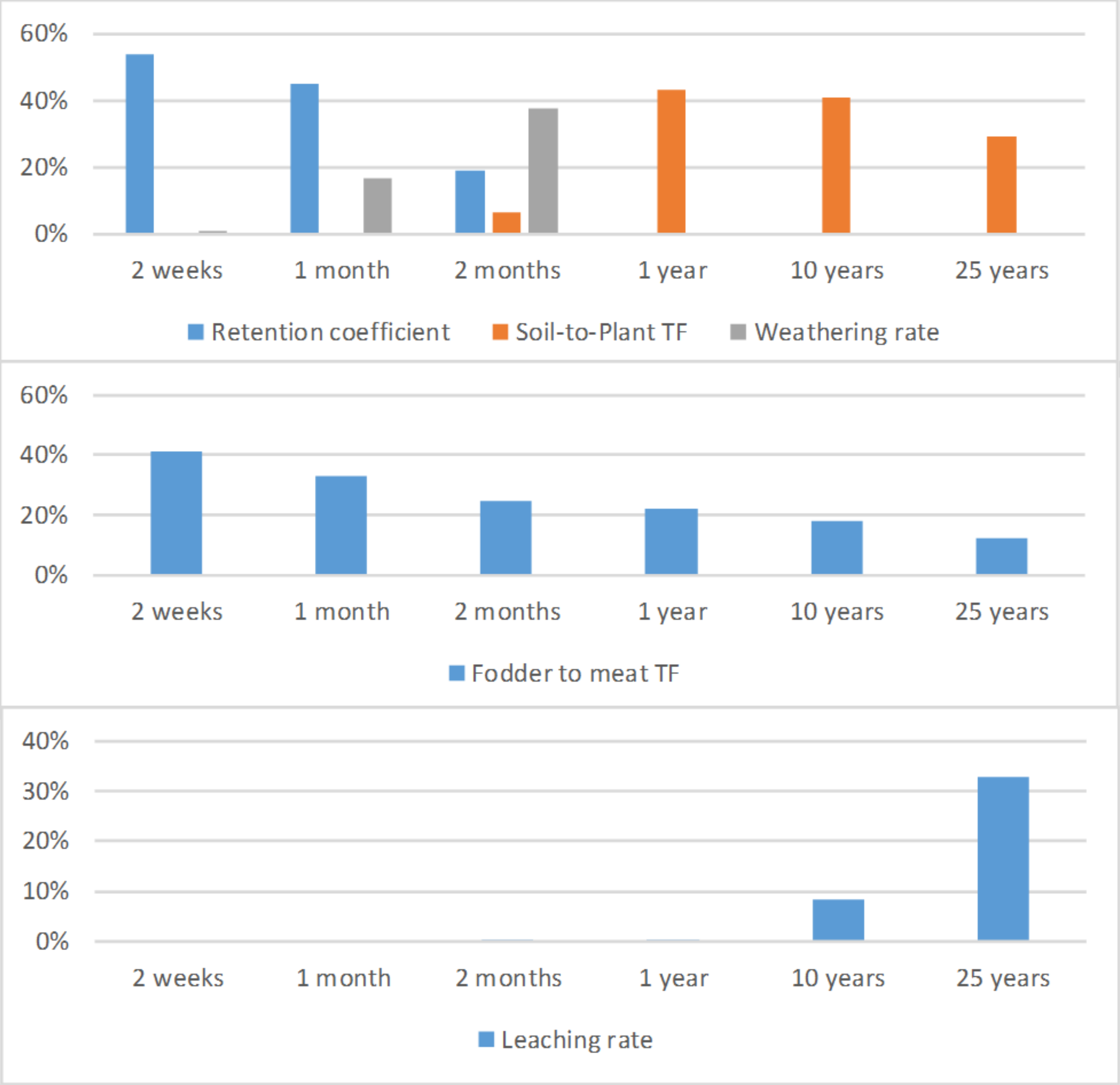


Figure A7.7 Effective Algorithm for Global Sensitivity Indices (EASI) as a function of time – Sr-90 lamb.

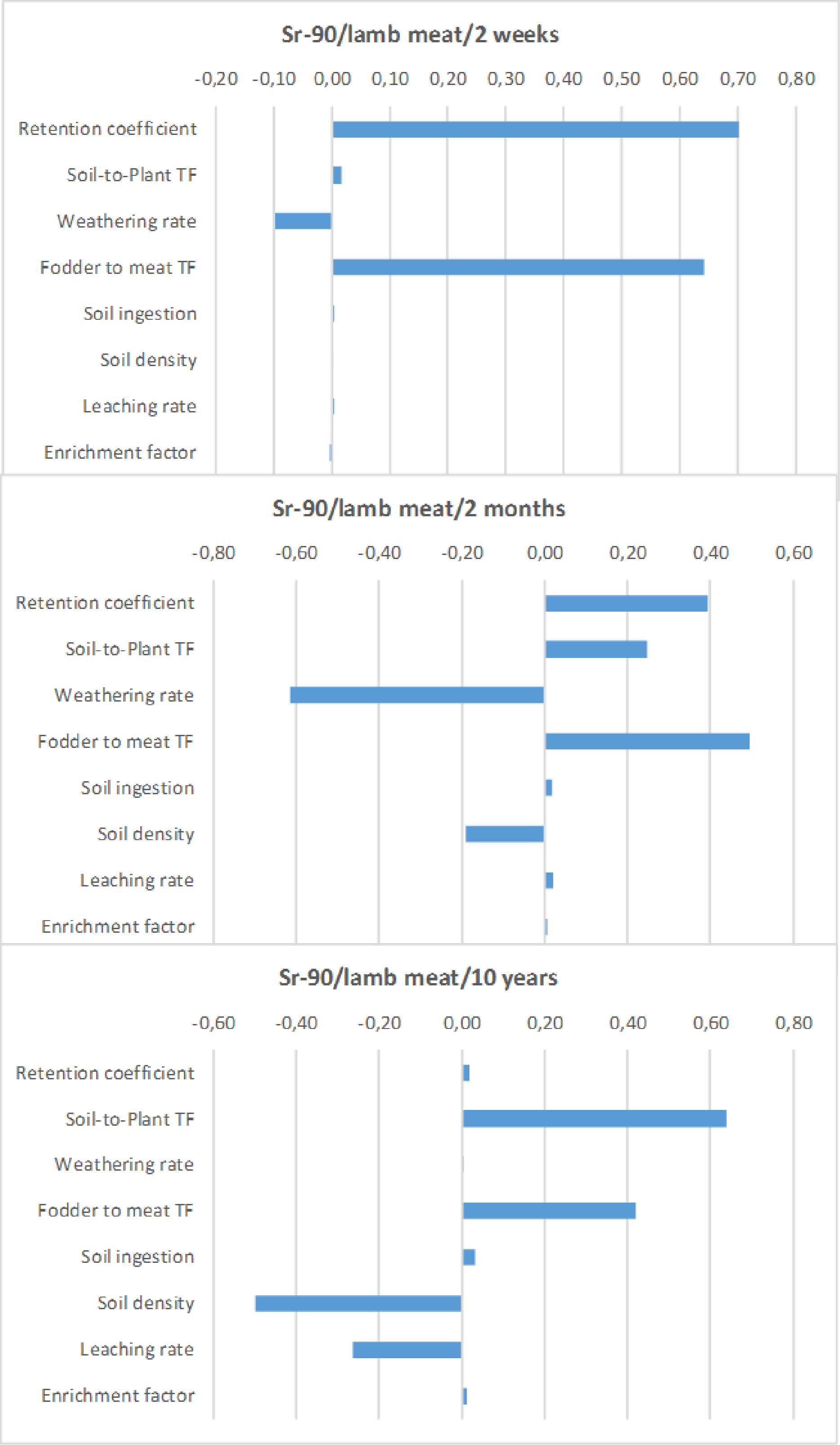


Figure A7.8. Spearman rank correlation coefficients between ECOLEGO parameters and output, for various time points; Sr-90 lamb.