

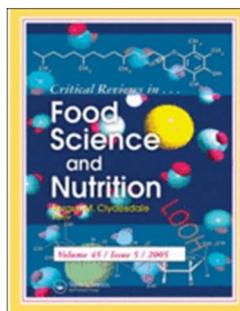
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Critical review of methods for risk ranking of food related hazards, based on risks for human health

Journal:	<i>Critical Reviews in Food Science and Nutrition</i>
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Complete List of Authors:	Van Der Fels-Klerx, H.J.; RIKILT WageningenUR, Van Asselt, ED; RIKILT WageningenUR, Raley, Marian; Newcastle University, School of Agriculture, Food and Rural Development Poulsen, Morten; Technical University of Denmark, National Food Institute Korsgaard, Helle; Technical University of Denmark, National Food Institute Bredsdorff, Lea; Technical University of Denmark, National Food Institute Nauta, Maarten; Technical University of Denmark, National Food Institute d'Agostino, Martin; Fera Science Ltd. (Fera), National Agri-Food Innovation Campus Coles, David; Newcastle University, School of Agriculture, Food and Rural Development Marvin, HJP; RIKILT WageningenUR, Frewer, Lynn; Newcastle University, School of Agriculture, Food and Rural Development
Keywords:	Risk prioritization, risk ranking, food safety, nutritional hazards, health impact

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Manuscripts

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3 Wageningen, 8 January 2016
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10 Dear Editor,
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12 We would like to thank you and the reviewer for the valuable comments and suggestions to
13 our manuscript entitled "Critical review of methods for risk ranking of food related hazards,
14 based on risks for human health" which we submitted to Critical Reviews in Food Science
15 and Nutrition. We appreciate a lot the suggestions given by the reviewer to improve our
16 manuscript.

17 We have revised the manuscript duly taking into account each comment made. In the Annex
18 you will find the itemized list of our revisions and responses. All co-authors have seen and
19 agree with the revisions.

20 We hope you will appreciate our revisions and approve the revised manuscript for
21 publication. In case of any question, please do not hesitate to contact me on the address
22 indicated below.
23
24

25
26 Sincerely, Ine
27

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Annex. Itemized list of responses.Reviewer: 1

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1. I urge authors to strengthen the discussion based on the findings of the literature review to provide readers with more than just an expose of the current methods available to rank risks. As it is mentioned in the manuscript, there is not a single method that can be applicable to risk ranking, but the authors must expand on this and provide directions on how to select an appropriate method for the goals of prioritization. A discussion on the differences of microbial, versus chemical and nutrition is also necessary – is there any of method that is more suitable to a certain type hazard or situation? Is it realistic (feasible) to think about a single method to rank microbial, chemical and nutrition risks? The strong discussion and conclusion are crucial and need to be included in the paper, to set it apart from the previously published report.

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Answer: Yes, we agree with the reviewer to expand on the issues of how to select an appropriate method; difference of methods for microbial, versus chemical and nutrition hazards etc.

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Adapted: In the revised version, we have added a strong discussion section, and wrote a stronger conclusion. To do so, we added a separate discussion & conclusion section to the paper addressing the issues mentioned by the reviewer as well as data needs of the methods; uncertainty; resource demands and communication.

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2. Another concern of this reviewer is the search strategy used and the fact that it seen to have missed at least three relevant risk ranking work. The FAO/WHO produce ranking (FAO/WHO, 2008) , the US Food and Drug Administration (FDA) produce risk ranking tool, and the COI report on foodborne illness from the USDA Economic Research Services (ERS, 2015), were not included in this review, but must. The work above are not necessary different methods, but are relevant enough to be included in this review. The FDA's fresh produce risk ranking tool deserves a special attention as it is the methodology behind FDA's rule on tracking high risk foods and offers a free online tool for ranking risks in produce . It is not clear if those references were not identified at all by the search or if they were excluded from the final list of candidates. Either way, it raises the question of whether other relevant work was not excluded in this process. This review would like to receive assurance that the search strategy was robust enough to not have missed other relevant work.

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Answer: If appears that the reviewer is not sure about the search strategy used in our study because three reports/papers he/she knows are not in the reference list of the paper. We would like to stress that not all references deemed relevant are given as examples in the body text and thus present in the paper's reference list.

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The FDA risk ranking tool, published by Anderson et al. (2011) has certainly been included in the review, classified as a MCDA method. It was however not provided as an example to the text and thus present in the reference list. The same goes for the FAO/WHO (2008) report on produce ranking. This report has been included in our review, but was not given as example in the body text.

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Adapted. In the revised version, the FDA method and the FAO/WHO report have also been addressed in the body text. Both studies have been added in the section of the their respective method category, being MCDA and expert judgment.

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The COI report from the USDA is published in the year 2015, which was out of scope of our literature study (which included publications up to and including 2013). The scientific paper (Hoffmann et al., Journal Food Protection 2012), that was published as part of the USDA study, was included in our study as relevant paper. The methodology was Col and QALY's.

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3. How each of the methods were classified is a little. For example, WTP, COI and HALY are, for this reviewer, a metric for risk ranking, not method. Authors should define better why and how they choose to classify the methods into those 14 categories, since there are many ways it could have been done.

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Answer: To the opinion of the authors, a methodology is a way of doing something, in particular doing it in a systematic way, with logical steps/arrangements. Therefore, Col, WTP and HALY were considered methods. The methods were divided into different categories based on the way they evaluated the hazards present and its severity as well as their combination to come to an assessment of the risk.

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Adapted: In the revised version, this has been made more clear, by adding the following sentence "All methods covered both presence of the hazard and its severity. Method categories differed in the way in which these two factors were evaluated and combined to come to an estimate of the risk."

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4. ...Authors must review the entire section on MCDA and make the necessary corrections. This reviewer recommends using as examples of MCDA methods from the papers published by Ruzante et al. (2010) and Fazil et al. (2008). Authors will see that preference functions (in addition to weights) are core to MCDA methods and must be selected when conducting a risk ranking. There are also several methods under the MCDA umbrella, which vary in complexity and might even allow for probabilistic modeling and sensitivity analysis. In addition, each of the methods has their own algorithm to calculate the "net flow," being more than just an addition (or multiplication of scores).

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Adapted: In the revised paper we have rewritten the entire section on MCDA methods, such to do the corrections and to strengthen that both weights and preference functions are core part of the method, and should be selected when conducting a risk ranking. The recommended citations were included as examples to the text.

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5. Line 16 and 646: this is not a systematic review, but a literature review.

Adapted

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6. Line 44: the statement in this line refers to practice or is it theoretical? Please make it clear.

Adapted, we added "both in practice and from theoretical calculations" to the sentence.

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7. Lines 48 to 50: include the FDA tool for produce (<http://foodrisk.org/exclusives/rrt/>) and give the exact url for iRISK. Also authors should make sure they list these tools again under the method they belong.

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Adapted, the section on MCDA methods has been extended to mention the FDA tool as an example of the MCDA method. The following sentence has been added: "A well-known example of a MCDA method for ranking pathogen-produce combinations is the Pathogen-Produce Pair Attribution Risk Ranking Tool (P³ARRT) developed by FDA (Anderson et al., 2011), which is free available (<http://foodrisk.org/exclusives/rrt/>)." Also, the URL for the iRISK tool has been corrected.

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8. Line 96: was the check random? If not please state how it was done and make it clear.

Adapted. We have added "randomly selected" to the sentence.

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9. Line 118: what the authors mean by type of tool? Please add between parentheses.

Adapted. The "type of tool" refers to a short description of the method or tool applied. This has now been indicated between parentheses.

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3 10. Line 144 - 148: make sure that in the text authors follow the order stated here. This
4 list of methods do not match the text that comes after.

5 *Adapted. The order of the sections describing each of the method categories has been*
6 *changed so to follow the order stated here. This implies that several entire sections have*
7 *been moved.*
8

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10 11. Line 198: make sure the subheadings are consistent throughout the text – see line
11 198 and 234, for example. And on this particular title for the subheading, it is really
12 focused on the risk manager, not on the broad group of stakeholders.

13 *Adapted. Subheadings have been made consistent, and focused on the risk managers. So,*
14 *we used “Perspective for use by risk manager” as subheading.*
15

16
17 12. Line 204: please make it more clear what this method entails. It was extremely
18 confusing to this author how it differs from just risk assessment. In my field of work,
19 for example, comparative risk assessments are the same as relative risk
20 assessments (see lines 178-179), but according to your review, CRA is a different
21 method that seems to restrict the comparison to fatalities. Please clarify the distinction
22 between risk assessment and CRA.
23

24
25 *Answer: In our study, comparative risk assessment were defined as methods that use*
26 *population attributable factors to estimate total effects of a risk factor – in this case a food*
27 *related hazards on numbers of dying related to diseases caused by that risk factor. CRA*
28 *make use of large epidemiological dataset. They clearly distinct from RA and relative RA*
29 *since they are not based on the total consumption of the hazard (via food). The term*
30 *‘comparative’ could indeed by used in different ways in literature, in this case it is not*
31 *identical to ‘relative’. Indeed, the part on relative risk assessment was missing in the original*
32 *paper, though covered in the introduction.*

33 *Adapted: We have one line to the CRA section to clarify the focus of CRA in our study: “CRA*
34 *is restricted to comparisons of deaths and it is, therefore, not comparable to a risk*
35 *assessment or a relative risk assessment.” Also, we have moved the lines on relative risk*
36 *assessment from the introductions, to the section on RA.*
37

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40 13. Line 239: please mention whether this is a qualitative, semi-quantitative or
41 quantitative method.

42 *Adapted. the sentence has been changed into : “Risk ratios or quotients refer to a*
43 *quantitative method in which estimates of exposure are divided by estimates of effect”.*
44

45
46 14. Line 263: lack of data seem to be an issue for all methods. If some are better than
47 other in dealing with this, please make the distinction, otherwise it worth mentioned
48 up front instead of under each of the methods.

49 *Yes, the reviewer is correct. Lack of data seems to be an issue for all methods. However, for*
50 *some methods it is more an issue than for others, particularly for RA and CRA and MCDA. In*
51 *the section referred to by the reviewer, it is not so much an issue of the three methods*
52 *mentioned and, therefore, we have deleted the two sentences on lack of data here. In the*
53 *discussion, we have added an entire section on the data needed by the different method*
54 *categories, and if they can deal with lack of data.*
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58 15. Line 296: typo – should be “and”.

59 *Adapted*
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16. Line 349: instead of “may be advisable” should say “is advisable”.

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3 *Adapted.*

- 4
5 17. Line 349 -350: updating ranks as new information becomes available is also a
6 general issue with all methods. As for the comment above, this is not the case for
7 some of the methods, please note otherwise stick to a general weakness statement in
8 the beginning or end of the article.

9
10 *Adapted. The statement of updating ranks as new information becomes available has been*
11 *removed from the COI section. Instead, it has been placed in the general discussion section,*
12 *but referring as a strength of all methods to which this is applicable. As part of the new*
13 *discussion section, the following sentence has been added “Methods most suitable for such*
14 *an automatic update are RA, risk ratio, risk scoring, risk matrices, COI, HALY, and MCDA. It*
15 *is more difficult to apply with CRA, WTP and expert synthesis”.*

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18 18. Line 376: Newsome et al (2009) and Chen et al (2013) are the same method – iRISK.
19 Use just one.

20 *Adapted.*

- 21
22 19. Line 378: one of the issues of DALY or QALY is also communication – it is hard for
23 stakeholder to understand that they mean – please list that as a weakness too.

24 *Adapted. The following sentence has been added “Also, stakeholders have difficulty to*
25 *understand the concept and what is meant by it”.*

- 26
27
28 20. Line 483: Havelaar et al. (2010) is not on the reference list – this reviewer did not
29 check all the references, but please make sure they are all there.

30 *Adapted. Havelaar et al (2010) has been added to the reference list. Also, all other*
31 *references have been checked and added/corrected.*

- 32
33 21. Line 521-522: are those subjective? Please make it clear how risk classes are
34 established in this method.

35 *Adapted. Yes indeed, those are subjective. This has been made clear by adding the*
36 *sentence “The division into these classes is subjective.” Furthermore, we added the following*
37 *line in the paragraph on strengths and weaknesses of this method. “However, the division*
38 *between different categories for presence of the hazard (e.g. low, medium high occurrence)*
39 *and its effects (e.g. low, medium, high toxicity) is subjective and, thus, other results are*
40 *obtained when with other divisions.”*

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44 22. Line 531: an extra “I” before “Alternatively”.

45 *Corrected.*

- 46
47 23. Line 536: experts to do what? Please finish the sentence

48 *Adapted. Sentence is confusing and therefore removed.*

- 49
50
51 24. Line 595-596: in MCDA judgement of stakeholders are not used to rank risks directly,
52 but are inputs on how to weight the different criteria and in establishing the
53 preferences.

54 *Adapted. This has been added when rewriting the MCDA section.*

- 55
56 25. Line 600: FAO/WHO produce risk ranking must be mentioned here too.

57 *Adapted. The FAO/WHO produce risk ranking method is presented as an example in the*
58 *section on expert synthesis.*

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3 26. Line 651-652: what are those methods that allow for microbial and chemical to be
4 ranked together? List here.

5 *Adapted. In the revised paper, the discussion section is extended. The following line has*
6 *been added to the discussion section: "Four of the eleven method groups can be applied to*
7 *all three types of hazards (microbiological, chemical and nutritional), either alone or in*
8 *combination, being MCDA, risk matrices, stated preferences, and expert synthesis."*
9

10
11 27. Line 658: MCDA are extremely data intense (see Ruzante et al., 2010 and Fazil et al.,
12 2008) – it all depend on your criteria.

13 *Adapted. We agree MCDA are data intense, and have removed MCDA here.*
14

15
16 28. Line 644: need to the stressed in the conclusion that uncertainties need to be clearly
17 stated as the majority of those methods do not provide this strength.

18 *Adapted. A sentence has been added to the conclusion stressing the importance on clearly*
19 *stating the uncertainties in data input.*
20

21 29. Table 3: this author disagree that MCDA methods require a moderate amount of
22 resources. Establishing weights and preferences with decision makers and getting
23 the necessary data to run the analysis is extremely time consuming. MCDA can be a
24 quite robust quantitative method, with even stochastic version – the authors seem to
25 have a very simplistic view of what MCDA method is. Graphs are another method for
26 communication for MCDA methods. And for COI, HALY and MCDA, the data needs
27 expressed on the last five rows of the table would be correct if the approach been
28 taken is "top-down," but incorrect if using "bottom-up", in this case you would need all
29 of the information mentioned in the last rows (see who iRISK works).
30

31 *Adapted. We agree with the reviewer that MCDA requires a high amount of time, data and*
32 *money, and have adapted this in Table 3. Also, graphs have been added as a method of*
33 *communication for MCDA methods.*

34 *Table 3 provides essential data needs. This has been changed in the heading. Indeed Col,*
35 *HALY and MCDA, can also use some of the other data sources mentioned when the*
36 *essential data is missing, and thus taking the bottom-up approach but this is less efficient.*
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Methods for risk ranking food safety and dietary hazards

RESEARCH PAPER

Critical review of methods for risk ranking of food related hazards, based on risks for human health

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Environmental Research Agency, Sand Hutton, York, North Yorkshire, YO41, 1 LZ.

14 ABSTRACT

15 This study aimed to critically review methods for ranking risks related to food safety and dietary
16 hazards on the basis of their anticipated human health impacts. A literature review was performed to
17 identify and characterize methods for risk ranking from the fields of food, environmental science and
18 socio-economic sciences. The review used a predefined search protocol, and covered the bibliographic
19 databases Scopus, CAB Abstracts, Web of Sciences, and PubMed over the period 1993-2013.

20 All references deemed relevant, on the basis of of predefined evaluation criteria, were included in the
21 review, and the risk ranking method characterized. The methods were then clustered – based on their
22 characteristics - into eleven method categories. These categories included: risk assessment,
23 comparative risk assessment, risk ratio method, scoring method, cost of illness, health adjusted life
24 years, multi-criteria decision analysis, risk matrix, flow charts/decision trees, stated preference
25 techniques and expert synthesis. Method categories were described by their characteristics,
26 weaknesses and strengths, data resources, and fields of applications.

27 It was concluded there is no single best method for risk ranking. The method to be used should be
28 selected on the basis of risk manager/assessor requirements, data availability, and the characteristics of
29 the method. Recommendations for future use and application are provided.

31 KEY-WORDS

32 Risk prioritization, risk ranking, food safety, nutritional hazards, health impact.

1. INTRODUCTION

Ranking of health risks related to food safety and nutrition is generally recognised as the basis for risk-based priority setting and resource allocation. It permits governmental and regulatory organisations to allocate their resources efficiently to the most significant public health problems (Van Kreijl et al., 2006). Within the area of food, risk is defined as the analysis and prioritization of the combined probability of food contamination, consumer exposure and the size of the anticipated public health impact of specific chemical, microbiological and/or nutritional hazards related to food. It is the combination of the *probability that a hazard may occur* in a food product and the *effect of exposure to the hazard on human health* (Codex Alimentarius 2001). Risk ranking has been applied to food safety monitoring programs and has shown to increase the efficiency of monitoring and to decrease inspection costs, both in practice and from theoretical calculations (Baptista et al., 2012; Presi et al., 2008; Reist et al., 2012).

To date, various risk ranking methods are available that prioritise food safety risks (Van Asselt et al., 2012). Methods vary from qualitative, through semi-quantitative, to quantitative methods (Cope et al., 2010; Van Asselt et al., 2012). Most methods are based on the 'technical' concept of risk being a function of presence of the hazard and severity of its impact on human health. However, some methods also involve other metrics, which may be considered in decision making, e.g., consumer perceptions of risk. In order to determine which methods are most suitable for ranking food related risks, it is important to follow a structured, objective and transparent approach to identifying and evaluating the available methods (van Asselt et al., 2013).

The aim of the current study was to review available methods for ranking risks associated with food on the basis of anticipated health impact, to characterize the methods and to provide recommendations for their use.

2. MATERIAL AND METHODS

2.1 Protocol for literature review

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8 61 A literature review was conducted which aimed to identify risk ranking methodologies that can be
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10 62 used to prioritize food related hazards, on the basis of the size of anticipated health impact. Hazards
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12 63 are defined as those agents that can be present in food and can negatively affect human health (Codex
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14 64 Alimentarius, 2001). Hazards included in this study were nutritional, chemical and microbiological
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16 65 hazards. The review covered methods from the fields of natural/life (food) science, socio-economic
17
18 66 sciences and food safety governance, published during the period 1993-2013. Risk ranking methods
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20 67 from fields outside food science (i.e. environmental sciences and socio-economic methods) were also
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22 68 included to evaluate their appropriateness for application in food science. The literature review
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24 69 followed the principles of a systematic literature review as described by EFSA (2010). A protocol for
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26 70 the structured literature review was defined *a priori*, including search strings and criteria for
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28 71 evaluation of the literature references (Annex 1).
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31 73 **2.2 Literature review**

32 74 33 75 Review methodology

- 34
35 76 a. Scientific articles were identified using the following bibliographic databases: Web of Science,
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37 77 Scopus, PubMed, and CAB Abstracts. In addition, the general search engine Google was used to
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39 78 search for reports, (the 'grey literature'), from relevant international and national organisations,
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41 79 authorities, and agencies (e.g., EFSA, EMA, WHO/FAO, FDA, Health Canada, OECD). The
42
43 80 literature search focused on papers and reports published in English.
- 44 81 b. The set of search strings was applied leading to an initial set of search results. All retrieved
45
46 82 references were stored in an Endnote database. Duplicates, a result of using four different
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48 83 bibliographic databases, were removed.
- 49 84 c. The references resulting from the initial set of search results were screened for their relevance to
50
51 85 the study objectives by applying the evaluation criteria. A two-tier approach was used. In tier 1,
52
53 86 the applicability of each reference to the review objective was determined by examining the title,
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55 87 abstracts and key-words of each reference. Based on this evaluation, the references were allocated
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57 88 to one of three categories and placed in the corresponding category of the Endnote database:
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8 89 - *Relevant for this study*: the reference was included;
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10 90 - *Possibly relevant for this study*: uncertain if the reference was relevant for the study;
11 91 - *Not relevant for this study*: the reference was determined to be out of scope.

12 92 An inter-observer check was conducted with a randomly selected subset (10%) of both selected
13 93 and excluded references.

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17 94 d. In tier 2, the full text of the references that were in the *Relevant* and *Possibly relevant* groups of
18 95 the Endnote database were retrieved. By reading the full texts, the papers/reports were evaluated
19 96 for their relevance to the field of interest and their quality using the evaluation criteria. When
20 97 deemed relevant, the reference was retained or moved to the group *Relevant* in the Endnote
21 98 database. When deemed not relevant, the reference was moved to the group *Not relevant* in the
22 99 Endnote database. Also at this stage, an inter-observer check was conducted; certain (randomly
23 100 chosen) literature references were evaluated by two experts from the team (from different
24 101 disciplines) in order to gain insights into the variation between the evaluation results of two
25 102 different experts.
26 103 e. Citations used in the reports/references of the final Endnote database were screened for additional
27 104 relevant references, published after 1993 (snowball citation), and steps c) and d) were applied to
28 105 them.
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41 107 Evaluation of references

42 108 For each reference stored in the *Relevant* category of the Endnote database, the risk ranking method
43 109 and its characteristics were evaluated in depth. A summary of the information obtained was stored in
44 110 an excel sheet, using a unique row for each reference. The format of the excel sheet was defined
45 111 beforehand, starting from the template developed by EFSA's BIOHAZ panel (EFSA, 2012b), but with
46 112 some modification to increase relevance to the objectives of the current study. Separate columns were
47 113 utilised for information about the reference (author names, title, abstract, journal, volume and page
48 114 numbers), and for storing the results from the critical evaluation of the risk ranking methods including:
49 115 the type of tool (short description); field of application (microbiological, chemical, and/or nutritional
50 116 hazards); what was ranked (e.g., specific food products); specific application area (e.g., pesticides);
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8 117 metrics, i.e., the type of method, with different sub-columns for each method category; model
9
10 118 structure (quantitative, semi-quantitative or qualitative); data requirements that describe the model
11 119 variables (e.g., human population data, or microbial numbers); method of data collection, describing
12 120 how the necessary data were collected and which data sources were used, and finally data integration,
13 121 describing how data were integrated in the application described in the reference. Based on this
14
15 122 evaluation, the references and the evaluated methods were categorised into different groups of
16
17 123 methods. The method categories were then described according to the following characteristics: scope,
18
19 124 application area, approach, strengths and weaknesses, and perspective for use by risk managers. At
20
21 125 this stage, reviews on risk ranking methods and other relevant literature were also consulted..
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28 128 **3. RESULTS**

31 129 **3.1 Literature search**

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33 131 At tier 1, application of the search strings and removal of duplicates led to the retrieval of the
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35 132 following numbers of references (Table 1): 6021 for chemical/toxicological hazards; 2932 for
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37 133 microbiological hazards; 1049 for nutritional hazards; 112 references using health adjusted live years
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39 134 method; and 3358 references using socio-economic methodology. The latter two method groups were
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41 135 considered since they could potentially include each of the three types of hazards (microbiological,
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43 136 chemical and/or nutritional hazards). The total numbers of references appearing in tier 2 are somewhat
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45 137 higher than in tier 1 due to snowballing citations. In total 253 references were judged to be relevant.
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48 139 **3.2 Description of risk ranking methods**

49 140 Based on the evaluation of the methods described in the relevant references, the risk ranking methods
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51 141 were classified, according to methodology, into the following categories: 1) Risk Assessment (RA), 2)
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53 142 Comparative risk assessment (CRA), 3) Risk ratio method, 4) Scoring method, 5) Risk matrix, 6) Flow
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55 143 charts (including decision trees and influence diagrams), 7) Cost of illness (CoI), 8) Health adjusted
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57 144 life years (HALY), 9) Multi criteria decision analysis (MCDA), 10) Stated preference methods, and
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8 145 11) Expert judgement. Table 2 shows the numbers of references that presented a particular method
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10 146 category, per type of hazard. All methods included both presence of the hazard and its severity.
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12 147 Method categories differed in the way in which these two factors were evaluated and combined to
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14 148 come to an estimate of the risk. In some instances, a combination of methods was applied, in which
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16 149 case the study was classified to its main category.

17 150 RA was by far the most frequently applied method. This method was applied to both chemical
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19 151 and microbiological hazards. For each of the chemical and microbiological hazards, about one third of
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21 152 all tier 1 references described the application of a RA to a particular hazard. However, as the
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23 153 procedure for each of the chemical and microbiological RA is comparable, only references describing
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25 154 guidelines for performing a RA were included. Risk ratio, scoring, risk matrices and flow charts were
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27 155 mostly applied to chemical hazards, whereas CoI, HALY, and expert judgments were mostly used for
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29 156 ranking microbiological hazards (Table 2). Ranking methods for nutritional hazards were fewer, and
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31 157 were mostly based on RA, CRA and expert judgement (Table 2). CRA, CoI, and stated preferences
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33 158 were the methods that were applied least frequently, with CRA used in three studies about nutritional
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35 159 hazards, and the latter two methods primarily applied to microbiological hazards. A few studies have
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37 160 considered both chemical and microbiological hazards in their ranking, applying methods for CoI and
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39 161 HALY. Summaries of each method and characteristics are presented in the following sections and in
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41 162 Table 3.

42 164 3.2.1. Risk Assessment

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44 165 Scope: A RA for a chemical or microbiological hazard aims to estimate the risk for human health
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46 166 associated with the presence of the hazard in one or more food products, and total food consumption.
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48 167 Numerous risk assessments have been applied to chemical and microbiological hazards in food. WHO
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50 168 (WHO, 2009) and Codex Alimentarius (2014) have provided guidelines regarding the principles and
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52 169 methods for the risk assessment of chemical contaminants and pathogens in foods. Although the
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54 170 application of the RA methodology is tailored to the hazard type, the principles for performing a risk
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56 171 assessment for both types of hazards are identical, consisting of the following four steps: hazard
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58 172 identification, exposure assessment, hazard characterisation, and risk characterization.

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8 173 Application area: Risk assessment is usually applied for one identified (chemical or microbiological)
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10 174 hazard occurring in a specific food commodity and for a predefined population, with the purpose of
11 175 characterizing the associated health risk. Apart from this, an important reason for conducting a RA is
12 176 to evaluate the impact of control measures to reduce the risk. If the results of different RA are
13 177 compared (e.g. for different hazards or different foods), the RA can be used for risk ranking.

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15 178 Approach: Various RA approaches for chemical and microbiological hazards in food were identified,
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17 179 applying different combinations of deterministic, probabilistic (or stochastic), qualitative, semi-
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19 180 quantitative, and quantitative modelling. Furthermore, different approaches were used for the exposure
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21 181 assessment and the hazard characterization steps. EFSA (2011) published an overview of procedures
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23 182 for current RA methods for dietary exposure of different chemical substances. The need for
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25 183 development of harmonized approaches, and future exploration of cumulative exposure assessments,
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27 184 is identified. In 2012, EFSA published its experiences gained with Quantitative Microbiological Risk
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29 185 Assessment (QMRA) studies (EFSA, 2012a).

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31 186 Strengths and weaknesses: In RA, all available scientific and technical information and data, as well as
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33 187 variability and uncertainties are systematically organized and analysed. It is a well-structured method,
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35 188 providing insights into what is known and what is not known. In particular, RA offers the opportunity
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37 189 to address uncertainties in a transparent way, e.g., *via* sensitivity analyses and/or modelling and
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39 190 simulation runs. It could be the most precise method to estimate risks, including the relevant
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41 191 uncertainties. However, a RA for one chemical or microbiological hazard usually requires a lot of
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43 192 time, data and knowledge. Ranking risks related to various hazards in food using outcomes of
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45 193 individual RAs will take even more resources and RAs are often hampered by a lack of quantitative
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47 194 data. Lack of data, selection of models to fit to the data, and assumptions that need to be made give
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49 195 rise to uncertainties in the outcomes. Recently, several tools for relative risk assessment for pathogens
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51 196 of pathogen-food combinations have been published. Examples of such tools applying quantitative
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53 197 methods are the swift QMRA tool (Evers and Chardon, 2010) and iRISK, which is a relative risk
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55 198 assessment system for evaluating and ranking food-hazard pairs (Chen et al. 2013, see [http://](http://https://irisk.foodrisk.org/)
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57 199 <https://irisk.foodrisk.org/>). An example of a semi-quantitative approach is Risk Ranger (Ross and
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59 200 Sumner, 2002) developed by Food Safety Centre (2010).

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8 201 Perspective for use by risk manager: Applied optimally, RA should disseminate key information
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10 202 regarding risk from exposure to food hazards to policy makers, decision makers and the public. RA are
11 203 very useful for providing insights into gaps in knowledge and issues associated with high levels of
12 204 uncertainty. However, they may not be suitable for risk ranking given the large amounts of data,
13 205 knowledge and resources needed.
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18 207 3.2.2. Comparative risk assessment

19 208 Scope: A Comparative Risk Assessment (CRA) analysis can estimate the number of deaths that would
20 209 be prevented in a given period if current distributions of risk factor exposure were changed to a
21 210 hypothetical alternative distribution (Danaei et al., 2009; Micha et al., 2012). In these papers, CRA is
22 211 restricted to comparisons of deaths and it is, therefore, not comparable to a risk assessment or a
23 212 relative risk assessment.
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30 213 Application area: Three applications of CRA have been found; each of them studied the impact of
31 214 dietary factors on disease mortality. Danaei et al. (2009) performed a CRA analysis for establishing
32 215 the preventable causes of death associated with dietary, lifestyle and metabolic risk factors in the
33 216 United States. Micha et al. (2012) used a CRA framework to develop methods for assessing the global
34 217 impact of specific dietary factors on chronic disease mortality. Lim and co-workers (2012)
35 218 investigated burden of disease and injury attributable to 67 risk factors (including chemical hazards
36 219 and nutritional imbalances) in 21 regions through application of a systematic analysis for the Global
37 220 Burden of Disease Study 2010. Although a CRA analysis as described below was not performed by
38 221 Lim et al. (2012), several elements of a CRA analysis were included.
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46 222 Approach: A CRA analysis is measured in population attributable fractions (PAFs), which describe the
47 223 total effects of a risk factor (direct/indirect) by reflecting the proportional reduction in deaths for each
48 224 disease causally associated with the exposure that would occur if the usual exposure distribution had
49 225 been reduced to the optimal minimum-risk exposure distribution. Input needed to determine the PAF
50 226 include: a) effect size (relative risk estimate) of the causal diet-disease relationship, b) optimal or
51 227 theoretical minimum-risk exposure distribution, c) dietary risk factor exposure distribution in the
52 228 population and, d) total number of disease-specific deaths (plus non-fatal events, when available) in
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8 229 the population. Data sources for obtaining these inputs include epidemiological studies, systematic
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10 230 reviews, meta-analysis, nationally representative nutrition surveys and mortality databases.

11 231 Strengths and weaknesses: A CRA analysis is a systematic assessment of unbiased data collected in
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13 232 national and international surveys as well as the peer reviewed literature. It allows for consistent,
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15 233 comparable and quantitative assessment of the global impact of risk factors on disease by sex- and
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17 234 age-specific groups. A CRA analysis requires knowledge and resources (manpower, money, data),
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19 235 which makes it expensive to perform. Unbiased data are also needed, e.g., to establish exposure
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21 236 distributions or causal diet-disease relationships, which may often not be easily accessible or available.
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23 237 The weights of different diseases are not considered. Uncertainties associated with a CRA analysis can
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25 238 be high because of data limitations.

26 239 Perspectives for use by risk manager: A CRA analysis offers a global assessment of the impact of
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28 240 dietary factors on disease mortality, which is very valuable for priority setting and policy making.
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30 241 However, with large and overlapping uncertainty ranges for the different risk factors, ranking of
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32 242 modifiable dietary risk factors may be difficult.

33 34 35 244 3.2.3. Risk ratio method

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37 245 Scope: Risk ratios or quotients refer to a quantitative method in which estimates of exposure are
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39 246 divided by estimates of effect. For this purpose, data are needed regarding the amounts of the hazard
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41 247 consumed (either the dose or the concentration) as well as a measure for the effect of the hazards that
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43 248 are studied.

44 249 Application: The risk ratio method has usually been applied to rapidly screen the risk of a range of
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46 250 chemical compounds in order to rank them. Most studies applied the method to rank pesticides,
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48 251 although five studies focused on microbiological hazards, and one study applied the method to rank
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50 252 both chemical and microbiological hazards.

51 253 Approach: For chemical contaminants, some references derive a Hazard Index, in which the Estimated
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53 254 Daily Intake (EDI) is divided by the Acceptable Daily Intake (ADI), Tolerable Daily Intake (TDI) or
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55 255 the acute Reference Dose (RfD) (Calliera et al., 2006; Oldenkamp et al., 2013; Sinclair et al., 2006).
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57 256 The Margin of Exposure (MoE) approach is another method in which exposure and effect are

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8 257 compared by dividing the NOAEL (No Observed Adverse Effect Level) or the BMD (Bench Mark
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10 258 Dose) by the EDI (Bang et al., 2012; Madsen et al., 2009; Rietjens et al., 2008). The Hazard Index
11
12 259 should be as low as possible, whereas the MoE should be as large as possible to obtain a low risk for
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14 260 human health. In general, the risk of pesticide residues for human health is ranked using the Hazard
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16 261 Index (e.g., Labite and Cummins, 2012; Sinclair et al., 2006; Travisi et al., 2006; Whiteside et al.,
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18 262 2008), whereas the risk of carcinogenic compounds is primarily ranked using MoE (Dybing et al.,
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20 263 2008; Lachenmeier et al., 2012). Applications of the method to microbiological hazards used different
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22 264 criteria, such as costs and effective dose.

23 265 Strengths and weaknesses: This method is easy to understand, and can be applied once concentration
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25 266 data and toxicological reference values are available; it only needs an estimate for both amounts of the
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27 267 hazardous material consumed and the effect of the hazard on human health. For emerging chemical
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29 268 hazards, e.g., nanomaterials, toxicological reference values are usually not available. .

30 269 Perspectives for use by risk manager: The method can give a quick answer on the risk of food safety
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32 270 hazards for human health, and can be applied to both chemical and microbiological hazards.

33 271 34 35 272 3.2.4. Scoring method

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37 273 Scope: This method is based on semi-quantitative scoring of both exposure and effect of the hazard on
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39 274 human health, followed by their multiplication (or – in one reference - addition).

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41 275 Application: Scoring methods provide a simple risk ranking method to characterize chemical hazards
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43 276 for subsequent categorization into particular groups (Aylward et al., 2013; Bietlot and Kolakowski,
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45 277 2012; Bu et al., 2013; Greim and Reuter, 2001; Taxell et al., 2013; van Asselt et al., 2013).

46 278 Approach: When a scoring method is applied, both exposure and severity (or effect) endpoints are
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48 279 considered. However, endpoints for exposure and effect can vary. Various endpoints have been used
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50 280 to estimate exposure, such as chemical transformation properties (degradability, half-life),
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52 281 mobility/distribution (such as bioaccumulation factors (BAF) or bioconcentration factors (BCF)),
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54 282 release, frequency of detection, and dose administered/concentrations. There is currently no scientific
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56 283 consensus on which endpoints to include and how to set criteria for classifying these endpoints.
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58 284 Consequently, selection of appropriate endpoints for a specific study is one of the steps in ranking

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8 285 risks according to a scoring method. Examples of endpoints for effect on human health might include
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10 286 acute toxicity, carcinogenicity, or reproductive toxicity, and can be based on LD50, MOAEL,
11 287 BMDL10 etc. Once criteria are set, endpoints are classified semi-quantitatively, e.g., using scores
12 288 from 1 to 3 or from 1 to 5, as applied in, for example Penrose et al. (1994).

15 289 After this classification system for endpoints has been established, data sources need to be found in
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17 290 order to assign scores for exposure and effect. These sources can be based on literature, available data
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19 291 and/or expert opinion. Scores subsequently need to be aggregated, which is mainly done by
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21 292 multiplying exposure and effect (see, e.g., Gamo et al., 2003; Juraske et al., 2007; van Asselt et al.,
22 293 2013), although one study added the scores (Penrose et al., 1994). Some references also employ a
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24 294 weighing system to weigh the various endpoints included in the assessment (Dabrowski et al., 2014;
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26 295 Juraske et al., 2007; Penrose et al., 1994; Valcke et al., 2005). A general framework for risk ranking
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28 296 that includes the choice of endpoints, weighing endpoints and aggregating the scores into a final risk
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30 297 score is depicted in Figure 1.

31 298 Strengths and weaknesses: This semi-quantitative method is easy to conduct once scores have been
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33 299 assigned to the model variables. Furthermore, it allows the inclusion of stakeholder perceptions in
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35 300 assigning the scorings and the importance (to each stakeholder) of each model variable is reflected by
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37 301 the weighting allocated to it. The assigned weights should then be clearly documented to guarantee a
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39 302 transparent approach.

40 303 Perspectives for use by risk manager: Stakeholders can use this method to obtain a clear overview of
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42 304 prioritized risks in relation to food safety hazards. The method has been used as input to the
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44 305 establishment of national monitoring programmes (VRC, 2010).
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48 307 3.2.5. Risk matrices

49 308 Scope: Just like the scoring methods, risk matrices also make use of scoring both exposure and effect
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51 309 endpoints. The difference between scoring methods and risk matrices is that, in the latter, the exposure
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53 310 and effect endpoints are not aggregated by multiplication or addition, but are depicted in a risk ranking
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55 311 matrix with effect on the one axis and exposure on the other.
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8 312 Application: This method is usually applied to chemical or microbiological hazards for which limited
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10 313 quantitative data are available. This method has, for example, been applied for ranking the risks of
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12 314 nanomaterials (O'Brien and Cummins, 2011; Sorensen et al., 2010; Zalk et al., 2009).

13 315 Approach: Both the likelihood of occurrence and the consequences of the hazard for human health are
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15 316 scored into one of several classes; see Figure 2 for an example. Classes that could be used for
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17 317 likelihood of occurrence are: almost certain, likely, possible, unlikely and rare. Classes that could be
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19 318 used for the consequences are: insignificant, minor, moderate, major and severe. The division into
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21 319 these classes is subjective. Then, risk classes are assigned to the combinations of Likelihood and
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23 320 Consequences, e.g., being L (low), M (moderate), H (high), and E (extreme), as shown in Figure 2.
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25 321 Risk classification may also be based on scores. Zalk et al. (2009), for example, classified
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27 322 nanomaterials based on scores for probability and severity, and the results were depicted in a risk
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29 323 matrix. The results can also be visualized using spider web plots, as conducted by, (e.g.), Ranke and
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31 324 Jastorff (2000), who classified various endpoints using scores from 1-4, and compared plots for the
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325 various compounds to obtain an indication of the most risky ones.

33 326 Strengths and weaknesses: The risk matrix method is qualitative or semi-quantitative, and thus less
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35 327 accurate than methods based on concentration data and dose-response relationships or toxicological
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37 328 reference values. It provides a visualisation for both presence of the hazard and its effects, giving
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39 329 direct insights into the way these two elements contribute to the overall risk of a hazard. For example,
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41 330 a hazard may present a high risk due to a high exposure, although its severity is low. Alternatively,
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43 331 due to its high toxicity, it may present a high risk rank despite low exposure. Matrices will give more
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45 332 information to the risk manager compared to other methods that produce a list of hazards according to
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47 333 the overall risk alone. However, the division between different categories for presence of the hazard
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49 334 (e.g. low, medium high occurrence) and its effects (e.g. low, medium, high toxicity) is subjective and,
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51 335 thus, other results are obtained when with other divisions.

52 336 Perspectives for use by risk manager: In case stakeholders prefer a graphical representation of the
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54 337 risks, this method can be used to visualize both the effect and the exposure of a hazard. This facilitates
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56 338 discussions amongst stakeholders regarding the risks of various hazards.

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8 340 3.2.6. Flow charts

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10 341 Scope: Flow charts or decision trees are based on a set of clearly defined questions or criteria. By
11 342 following these, , the hazards can be classified into different categories (e.g. high, medium or low)
12 343 with respect to their risk for human health.

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15 344 Application: Flow charts or decision trees can be used for various purposes. In general these methods
16 345 are used to obtain a qualitative indication about the risks associated with hazards. Haase et al. (2012),
17 346 for example, established a decision tree for nanoparticles to determine whether a full risk assessment is
18 347 required or not. EFSA described guidelines for classifying chemical hazards as negligible, low,
19 348 medium, and high risks (EFSA, 2012c, 2012d).

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21 349 Approach: A flow chart is generally based on several questions that need to be answered in order to
22 350 arrive at a certain risk class. Questions can be based on the likelihood that specific chemicals or
23 351 microbiological hazards are present in the study object; evidence of occurrence or incorrect practice in
24 352 the food chain, the toxicological profile, and the outcome of national monitoring programmes (EFSA,
25 353 2012c, 2012d). Eisenberg and McKone (1998) used a Classification and Regression Tree Algorithm
26 354 (CART) to specify the chemical and environmental properties and Monte Carlo simulations to
27 355 estimate human exposure. Schmidt et al. (2011) utilized a decision support system (DSS) to rank
28 356 genetically modified organisms (GMOs), based on a decision tree and rules, indicators and baselines,
29 357 and thresholds (such as the LD50) (Schmidt et al., 2011). DSS may also be combined with multi-
30 358 criteria decision analysis (MCDA). Critto (2007), for example, utilised a DSS system to evaluate
31 359 ecological observations and ecotoxicological tests for contaminated sites and then incorporated
32 360 MCDA and expert judgments into the ranking. This approach might also be used for ranking food
33 361 safety risks.

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41 362 Strengths and weaknesses: Flow charts/decision trees present a straightforward method with clear
42 363 questions for which only qualitative information is needed, although quantitative information can be
43 364 used where available. The method can, thus, be used for a quick screening of food safety hazards, in
44 365 order that the most relevant ones may subsequently be investigated in more detail. However, this
45 366 method strongly depends on expert input and it is, therefore, essential to perform a rigorous expert
46 367 elicitation study. Furthermore, this type of method is vulnerable to being less transparent than other

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8 368 methods, as it is not always clear why hazards end up being classified as a high, medium or low risk.
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10 369 Therefore, for each hazard classified based on a decision tree or flow chart, the underlying reasons for
11 370 the answers should be clearly documented in order to obtain a transparent classification.

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13 371 Perspectives for use by risk manager: It is important to set up the right questions for inclusion in a
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15 372 flow chart/decision tree based on expert judgment and scientific evidence, which may be challenging
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17 373 to achieve. However, once a decision tree has been drafted, it is easily applicable for stakeholders to
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19 374 classify hazards into high, medium and low risks.

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22 376 3.2.7. Cost of Illness method

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24 377 Scope: The underlying research objective of the Cost of Illness (CoI) approach is distinct from those
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26 378 of the methodologies described so far. CoI studies acquire data for conducting economic analysis in
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28 379 order to obtain a ranking in terms of how society might allocates scarce resources when addressing
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30 380 food-related hazards. The procedure involves calculating the directs costs to society related to disease
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32 381 and death due to chemical, microbial and/or nutritional hazards. It can be applied wherever there are
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34 382 quantitative data relating to the impact of disease (severity and duration; mortality) and sufficient cost
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36 383 data for calculating resultant treatment costs and loss of income. Subject to data availability, it is
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38 384 possible to compare large numbers of food risks.

39 385 Application area: This approach can be applied for comparing diseases (Gadiel, 2010), for food-
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41 386 disease combinations (Batz et al., 2011), and for supply chain analysis of a single food-disease
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43 387 combination (Miller et al., 2005).

44 388 Approach: The starting point of this quantitative method is the construction of a separate disease
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46 389 outcome tree (or equivalent) for each illness under consideration. This will show the numbers (and
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48 390 proportions) of the affected population who experiences each type of impact, defined as the disease
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50 391 severity class. A critical point is whether it is restricted to acute effects, or whether long-term effects
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52 392 (sequelae and deaths) are also included. This will be particularly important for diseases for which
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54 393 some affected individuals will experience life-long disease, or where medical problems may be latent
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56 394 for a period (e.g., toxoplasmosis).

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8 395 If possible, the disease outcome tree is populated directly from existing data sources. However, data
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10 396 for disease incidence and attribution to a specific food source is often incomplete. The problems with
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12 397 inadequate or missing data are sometimes overcome by expert elicitation of (ranges of) parameter
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14 398 values (e.g., Batz et al., 2012; Golan et al., 2005). To address uncertainty caused by inadequate data,
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16 399 sensitivity analysis (e.g., Batz et al., 2011) or frequency distributions can be used in Monte Carlo or
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18 400 stochastic simulation models (Lake et al., 2010; Kemmeren et al., 2006). The costs incurred at each
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20 401 state are calculated, often including the categories of direct health costs, indirect health costs, and
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22 402 indirect non-health costs.

23 403 CoI studies generally make use of discounting by which the value of earnings and payments incurred
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25 404 in the future are expressed in terms of their present value. They are expressed as a given amount of
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27 405 money invested today at a given interest rate (or discount rate) (Crutchfield et al., 1999). By definition,
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29 406 discounting does not apply to the costs of health effects whose duration is shorter than one year,
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31 407 whereas other end-points, such as life-long disabilities, are strongly affected by discounting. Hence,
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33 408 the effect of discounting will differ per hazard (Kemmeren et al., 2006) and the rate of interest
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35 409 selected.

36 410 Strengths and weaknesses: The CoI method employs readily available and reliable data (Buzby et al.,
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38 411 1996) and the calculations are transparent and relatively simple. The same disease incidence data are
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40 412 used in HALY calculations so it is relatively efficient to produce both sets of rankings at the same time
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42 413 and they are, to some extent, complementary. A combined risk ranking can also be produced. A CoI
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44 414 ranking diverges from most measures of disease severity or social welfare (Golan et al., 2005) because
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46 415 CoI estimates are restricted to market goods. Therefore, apart from medical costs, the measures
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48 416 excludes non-workers, and do not address perceived quality of life including factors such as pain and
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50 417 stress (Golan et al., 2005). A further important weakness relates to the lack of accurate public health
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52 418 and attribution data, which is the biggest cause of uncertainty in CoI estimates. The results are
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54 419 dependent on the assumptions made *inter alia* about medical outcomes and the prevailing labour
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56 420 market.

57 421 Perspectives for use by risk manager: CoI is a well-tried technique with well-understood limitations
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59 422 relating to missing data, and failure of the approach to adequately include non-working members of
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8 423 society and quality of life impacts. Large numbers of risks can be ranked. The process appears highly
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10 424 transparent, but it should be remembered that the cost coefficients and incidence data may be derived
11 425 from inadequate data, so sensitivity analysis is advisable. Due to non-standardisation of technique (e.g.
12 426 different components, and assumptions), comparability between studies is awkward.

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16 427 3.2.8. Health adjusted life years (Burden of Disease)

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18 428 Scope: 'Health adjusted life years (HALY)' are nonmonetary health indices, where the actual health of
19 429 an individual is compared with a perfect health situation (usually on a scale from 0 to 1) and this score
20 430 is then multiplied by the duration of that health state. A descriptive summary of the various HALYs is
21 431 presented by Mangen et al. (2014).

22 432 Application area: HALY measures may be applied when the ranking of hazards is to consider the level
23 433 of human disease or loss of productive capacity for the exposed population, i.e., the burden of disease.
24 434 HALY estimates such as disability adjusted life years (DALYs) or quality-adjusted life years
25 435 (QALYs) may be used as the only parameter for risk ranking, but are often included as one of several
26 436 parameters in a risk ranking model. The DALY method was developed at the WHO, and the Global
27 437 Burden of Disease (GBD) study is the most often referenced source of disability weights for specific
28 438 disease outcomes (www.who.int/healthinfo/global_burden_disease/metrics_daly/en/). The HALY
29 439 approach has been applied to rank different pathogens and chemical contaminants in the same food
30 440 category, different hazard-food category combinations, or summarised and ranked for different food
31 441 categories. Estimates of DALYs or QALYs have also been used to rank waterborne contaminants in
32 442 lakes or water supplies as well as for ranking human risk factors in general.

33 443 Approach: Data are required for estimating the number of cases with the most relevant types of acute
34 444 illnesses, chronic sequelae and mortality (also termed health outcomes) arising from exposure to the
35 445 hazards under consideration. Different types of hazards (chemical, microbiological or nutritional)
36 446 require different types of data and modelling approaches (Crettaz et al., 2002; Hofstetter, 2002;
37 447 Mangen et al., 2010; Mangen et al., 2014; Pennington et al., 2002), but after the final DALY/QALY
38 448 calculations have been made, the risks estimates should be readily comparable. DALY/QALY
39 449 estimates may also be included in several of the other risk ranking methods such as RA (Howard et al.

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8 450 (2007); Newsome et al. (2009)), CRA (Lim et al. (2012)), MCDA (Ruzante et al. (2010)), risk
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10 451 matrixes, flow charts/decision trees or in expert syntheses.

11 452 Strengths and weaknesses: HALY methodologies readily allow comparisons between very different
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13 453 types of hazards, not only food related hazards but all types of human risk behaviour over time and
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15 454 geographical regions as presented by the Global Burden of Disease Study 2010 (Lim et al., 2012) and
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17 455 ECDCs initiative for developing methodologies for measuring current and future burden of
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19 456 communicable diseases (Mangen et al., 2014).

20 457 DALYs and QALYs are semi-quantitative estimates based on disability scoring, and their accuracy is
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22 458 highly dependent on the quality of input data and risk assessment models used for estimating the
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24 459 incidences of relevant health outcomes. In the applied studies, the methods for estimating the
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26 460 incidences of relevant health outcomes varied widely. The estimated DALY or QALY values seem to
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28 461 be relatively precise quantitative estimates, and there is a risk of over-interpretation of the relative
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30 462 differences, if the level of uncertainty is not addressed. A general methodological weakness is
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32 463 inadequate evidence to estimate the incidences of chronic disability, especially in cases with few or no
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34 464 symptoms during the acute phase of a disease. Another methodological weakness is that the concept of
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36 465 DALYs assumes a continuum from good health to disease, disability, and death which is independent
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38 466 of time – a concept not universally accepted. Also, stakeholders have difficulty to understand the
39
40 467 concept and what is meant by it.

41 468 Perspectives for use by risk manager: Tools are readily available for calculating DALYs for a range of
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43 469 infectious diseases including foodborne zoonoses in the EU (BCoDE tool from ECDC). If RA or
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45 470 models for estimation of reported cases are available, the resources needed to estimate DALYs are
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47 471 moderate. However, development of RA models to estimate the number of diseased individuals can in
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49 472 some instances be very time-consuming.

50 473 DALY or QALY estimates can be viewed as an economic measure of human productive capacity,
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52 474 enabling ranking of the 'societal production losses' related to the included hazards. If HALY estimates
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54 475 from different studies are to be used in risk ranking, then differences in the methodology employed
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56 476 and the comparability of the studies must be considered. For monitoring purposes, risk ranking models

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8 477 estimating HALYs can be constructed so that yearly input of surveillance and population data can be
9 478 entered, as done for the food borne pathogens in the Netherlands (Bouwknegt et al., 2013).

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15 481 3.2.9. Multi-Criteria Decision Analysis (MCDA)

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17 482 Scope: MCDA is an approach which has the potential to evaluate multiple - often conflicting - criteria
18 483 in decision making. It allows for comparison of different risks on common basis, by simultaneous
19 484 consideration of technical information, uncertainty and different stakeholder preferences, both
20 485 quantitative and qualitative data, and the integration of large amounts of complex information. .

21 486 MCDA helps structuring and solving problems, such to enable making more informed and better
22 487 decisions. In the context of risk ranking, important criteria utilized in food safety can be identified
23 488 through a process of expert or lay consultation, which may include not only public health impacts but
24 489 also perception, costs – an in case of interventions – also weight of evidence, and practicality
25 490 associated with the interventions

26 491 Application area: MCDA can be applied to any range of problems,
27 492 which can be defined in terms of a common set of criteria. As the scientifically ‘best’ solution may be
28 493 inadequate in terms of acceptability to society, utilize resources which or not available, or be sub-
29 494 optimal in terms of allocating resources, stakeholder methods are sometimes used to capture the
30 495 preferences of consumers, citizens and/or experts. MCDA which combines expert judgement across a
31 496 range of relevant criteria appears to be the second most popular method for relative risk ranking of
32 497 microbiological hazards, after RA.

33 498 Approach: MCDA is a semi-quantitative method in which a range of different criteria are identified
34 499 against which each problem is assessed. Participants, either experts, stakeholders or lay people (Fazil
35 500 et al., 2008), can be supplied with technical information in relation to each risk criterion to assist their
36 501 deliberations. The selection of preference functions and weights are an integral and core part of the
37 502 MCDA methodology and must be selected when conducting a risk ranking. An example is provided
38 503 by Ruzante et al. (2010) who utilized the method to develop a prioritization framework for foodborne
39 504 risks that considered not only public health impacts but also market impact, consumer risk acceptance
40 505 and perception, and social sensitivity. Another well-known example of a MCDA method for ranking

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8 505 pathogen-produce combinations is the Pathogen-Produce Pair Attribution Risk Ranking Tool
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10 506 (P³ARRT) developed by FDA (Anderson et al., 2011), which is available free
11 507 (<http://foodrisk.org/exclusives/rrt>). Fazil et al. (2008) applied MCDA for the ranking of food safety
12 508 interventions, considering amongst others cost, effectiveness, and weight of evidence. MCDA
13 509 methods and applications vary in their complexity; they may even allow for probabilistic modelling
14 510 and sensitivity analyses. Recently, alternative methods for performing a MCDA have been developed
15 511 and employed, e.g., by Havelaar et al. (2010), in order to minimise the biases linked with experts'
16 512 direct weighting of the MCDA criteria.

17 513 Strengths and weaknesses: MCDA allows consideration of stakeholder perceptions by using the
18 514 weights and preference functions they assign to the various criteria in the analysis. Furthermore,
19 515 economic impact or other criteria that are deemed relevant can be included, in addition to human
20 516 health criteria. This makes the method broadly applicable, allowing risk assessors/managers to
21 517 determine the impact of various criteria on the overall risk ranking of hazards. This method, therefore,
22 518 allows inclusion of subjective elements that may also be important for risk managers to include in their
23 519 decision making processes, depending on the aim of the ranking exercise. Alternative scenarios using
24 520 weights and preference functions for various input factors can be compared. However, MCDA
25 521 outcomes are more difficult to communicate compared to more straightforward methods such as risk
26 522 matrices or scoring methods, as various criteria are included, which are weighted and prioritized
27 523 differently. Furthermore, this method needs expert or stakeholder input in order to derive the weights
28 524 and preference functions for the criteria. Therefore this method has weaknesses that are linked to the
29 525 elicitation of information from experts (see below), i.e., the need for having rigorous, auditable
30 526 methods to identify experts; high demand for resources (as training of experts in these methods and
31 527 specialised risk analysts and modellers may be needed); the need to consider how to elicit experts'
32 528 own uncertainties regarding their views, opinions, judgments; and - last but not least – the need to
33 529 consider possible ways to combine individual opinions without masking variability in the experts'
34 530 views.

35 531 Perspectives for use by risk manager: This systematic method is very valuable in cases where
36 532 stakeholder perceptions are required to be included in the risk ranking, as weights and preference

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8 533 functions can be assigned to the various model variables. This method also allows the inclusion of
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10 534 factors other than effect and exposure endpoints, e.g. from the social-economic field, or in terms of
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12 535 policy development, which makes it a very versatile tool. The application of MCDA will provide a
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14 536 single number for ranking. However, the underlying calculations can be difficult for the non-expert to
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16 537 understand for those without expertise in the methodology.

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18 19 539 3.2.10. Stated preference methods

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21 540 Scope: Stated preference methods could be used to elicit the preferences of individuals (citizens and
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23 541 households) for reducing the risk from a range of food-related diseases. When aggregated they show
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25 542 society's preferences for risk reduction. These methods take into account the concerns and perceptions
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27 543 of society and, consequently, the ranking produced may be different from that produced by experts on
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29 544 technical grounds alone.

30 545 Application area: There is a relatively long history of the use of stated preference techniques for
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32 546 valuing non-market goods in the analysis of environmental problems. So far, their application in
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34 547 ranking food safety risks is limited and largely confined to valuing individual disease reduction
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36 548 measures or comparing alternative risk management options within single food-disease problem, see
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38 549 e.g., Mørkbak & Nordström (2009) and Miller et al. (2005). Golan et al (2005) concluded that, at
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40 550 present, there is not a coherent set of guidelines for conducting such studies, making comparability
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42 551 between studies difficult. In theory, these methods could be used to rank diseases, disease-food
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44 552 combinations, or stages in supply chains. However, it is a complicated technique to use, which might
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46 553 explain the lack of use for ranking more than a small number of alternatives.

47 554 Approach: Using stated preference methods, a simulated market is constructed and monetary values
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49 555 are derived from hypothetical questions. The methods include *stated preference* techniques
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51 556 (*contingent valuation* and *discrete choice experiments*) and averting behaviour or preventative
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53 557 expenditure, which is the cost of preventing illness. In contrast to the CoI approach, stated preference
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55 558 methods include the value individuals place on other factors for which no markets exist such as, for
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57 559 instance, (not) experiencing pain. Stated preference methods are also able to include the value of lost
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59 560 health in people who are not in the labour force (e.g. retired) who are excluded from CoI calculations.

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8 561 One of the stated preference methods, willingness to pay (WTP) rests on the observation that people
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10 562 make trade-offs between health and other goods and services. The approach elicits the resources an
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12 563 individual is willing to give up for a reduction in the probability of encountering a hazard that will
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14 564 compromise their health (Golan et al., 2005). As an example, Mørkbak and Nordström (2009)
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16 565 conducted a choice experiment to elicit WTP for campylobacter-free chicken as compared to the
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18 566 alternatives, non-labelled chicken and outdoor-reared chicken; in other words, the WTP for higher
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20 567 food safety compared to the current level. This approach defines the choices which individuals make
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22 568 in terms of the levels of key attributes (such as high/low price, probability of illness etc) which are
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24 569 associated with each of the goods being compared.

24 570 Strengths and weaknesses: WTP is generally viewed as the most complete and correct economic
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26 571 welfare measure of the benefits of food safety policies. This is because, like CoI, WTP includes the
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28 572 cost of treatment and lost productivity but also (unlike CoI) changes in consumer welfare such as pain,
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30 573 distress and inconvenience (Hoffmann, 2010). Both individual and societal WTP can be calculated. A
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32 574 useful feature is that stated preferences may be linked to participant profile revealing which societal
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34 575 groups (e.g., by age, background) ranks a particular risk most highly (see Haninger and Hammitt
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36 576 (2011) for an example). The aggregated value of benefits (or societal WTP) of food safety (e.g.,
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38 577 reduced risks) can be compared with the costs for achieving them since both costs and benefits are
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40 578 expressed in monetary units.

40 579 However, WTP is a difficult technique to apply, and is prone to errors and bias unless conducted
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42 580 meticulously. Experience so far has been in comparing only 2 to 4 alternative risks. It may be possible
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44 581 to elicit mean WTP for a larger number of risks, but the scope of choice experiments may be limited
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46 582 by the capacity of participants to choose between a large number of choice sets encompassing many
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48 583 attributes. Moreover, WTP reflects the ability to pay, and implicitly assumes that the existing
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50 584 distribution of resources in society is acceptable (Golan et al., 2005). However, because WTP studies
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52 585 can produce results segmented by sub-population, they may draw attention to unequal distributional
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54 586 impacts which should be considered in policy making.

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8 587 Perspectives for use by risk manager. These techniques provide a means to incorporate societal
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10 588 preferences in ranking and decision making. However, experience in the food safety field as yet is
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12 589 only modest, and there is scope to develop techniques still further.

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17 592 3.2.11. Expert judgement

18 593 Scope: Expert judgement-based methods elicit rankings from citizens, stakeholders or other experts,
19 594 and have the potential to produce a systematic and transparent ranking of risks.

22 595 Application area: Three principal applications of judgement-based risk ranking were identified: a)
23 596 achieving a ranking when there are data gaps, b) reconciling the diverse information streams and
24 597 considerations encountered in multi-attribute problems, and c) incorporating societal values (e.g.
25 598 (Moffet, 1996). The inclusion of public perceptions, priorities and values may result in a different
26 599 ranking being reached to that derived from using scientific experts alone. This might reflect public
27 600 concerns such as whether the distribution of costs and benefits is equitable, the characteristics of the
28 601 people likely to be affected (e.g. children or elderly people), whether exposure to the risk is voluntary
29 602 or involuntary, and whether there is 'dread' or fear of a catastrophic impact (DeKay et al., 2005).

37 603 Approaches: A variety of methods is available, for application in workshops or in surveys, which may
38 604 be characterised by the flows of information which take place between the participants and the
39 605 research team (Rowe and Frewer, 2005). There may be a one-way flow of information from experts
40 606 (or other stakeholders) to researchers, which aims to capture participants' existing knowledge and
41 607 experience. Alternatively, there may be a two-way flow, whereby participants are provided with
42 608 detailed scientific and socio-economic information on which to base their deliberations and ranking,
43 609 which is finally communicated to the researchers. Formal semi-quantitative techniques exist to
44 610 combine divergent data sources, e.g., MCDA and the Carnegie-Mellon approach. In MCDA, the
45 611 judgement of stakeholders is used to allocate weights and potentially also on the way to weight the
46 612 different criteria and in establishing the preferences to the different attributes whereas the Carnegie-
47 613 Mellon approach produces risk rankings. . Approaches also vary according to whether they involve
48 614 experts or lay people, the amount of technical information about risks and impacts that is provided to

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8 615 assist study participants, whether the approach is qualitative or semi-quantitative, and whether or not
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10 616 the process involves deliberation among participants. Four approaches were identified:
11 617 - Expert elicitation, defined as a set of formal research methods used to characterize uncertainty
12 618 about scientific knowledge and to provide alternative parameter estimates when there are
13 619 meaningful gaps in available data (Batz et al., 2012). Commonly used approaches are
14 620 workshops and the Classical Delphi method (Van der Fels-Klerx et al., 2002).
15 621 - Survey based on existing knowledge of lay or expert participants (i.e. minimal technical
16 622 communication during the study), as applied by, e.g., Schwarzinger et al. (2010) and Harrington
17 623 (1994).
18 624 - Ranking achieved through deliberation only, or deliberation with supporting technical
19 625 information (e.g. focus group or workshop). Although the ranking process may be restricted to a
20 626 panel of experts considering scientific data only (e.g. FAO/WHO, 2008), there is also the
21 627 possibility to involve lay people and thus capture societal values.
22 628 - Carnegie-Mellon approach which was specifically developed as a standardised procedure by
23 629 which several risks could be ranked, and involves the elicitation of the explicit preferences of
24 630 lay groups (DeKay et al., 2005). The basic procedure requires expert technical inputs to define
25 631 and categorize the risks to be ranked, to select attributes by which the risks are characterised,
26 632 and to prepare risk summary sheets to assist deliberations on each risk (Florig et al., 2001).
27 633 - Ranking of risks is performed by lay people (not experts) in a workshop setting according to
28 634 their levels of concern about the risks, having considered the information provided on the risk
29 635 summary sheets. If used, weights for each attribute are obtained from each participant and
30 636 reflect social value judgements. The procedure used for weighting is much simpler than that
31 637 typically used in MCDA (DeKay et al., 2005).
32 638 Strengths and weaknesses: Judgement-based methods provide additional information to that of
33 639 technical assessments, e.g., when a problem is poorly understood, or technical data are incomplete.
34 640 The outputs commonly include a narrative component which can make explicit the interpretations and
35 641 assumptions which underlie the final ranking, as well as identifying the difficulties and uncertainties
36 642 which determine its limitations. They also provide a means of engaging the general public in

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8 643 evaluative and decision-making processes and of incorporating societal preferences for different
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10 644 alternatives. However, judgement-based methods require a very careful design if they are to provide
11 645 valid outcomes. Biases are introduced by a number of means including: inappropriate selection of the
12 646 participants; the framing of the problem(s) for consideration; the way the process is conducted such
13 647 that the whole range of opinions may not be elicited and recorded, and the content of the technical
14 648 information that is presented to participants (e.g. bias, comprehensibility, acknowledgment of its
15 649 limitations). Due to this need for meticulous preparation the method is often resource intensive.
16 650 Furthermore, a qualitative analysis of data (if required) makes heavy time demands both in the
17 651 transcription of audio recordings and their subsequent (thematic) analysis.
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19 652 Perspectives for use by risk manager: Unless judgement-based methods are planned and executed well
20 653 there is a danger that they will be biased and unreliable. Depending on the specific method, the output
21 654 may be a simple ranking, but could also be a lengthy narrative which, though having explanatory
22 655 power, requires lengthy consideration. These methods can provide input in cases where crucial data
23 656 are missing, and a decision needs to be made. Also, they could provide a means of incorporating
24 657 societal values into risk ranking.
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39 660 **DISCUSSION AND CONCLUSIONS**

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42 662 A literature review has been performed on methodologies for ranking risks related to chemical,
43 663 microbiological and nutritional hazards in food, on the basis of their anticipated effects on human
44 664 health. The results showed that a range of risk ranking methodologies has been applied depending on
45 665 the purpose of the specific study. They have been grouped into eleven main categories, determined
46 666 primarily by the type(s) of hazard that can be ranked, data needs, and uncertainty. Some methods
47 667 allow ranking of different hazards types (chemical, microbiological), whereas others allow ranking
48 668 only within one hazard category.
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50 669 Four of the eleven method groups can be applied to all three types of hazards (microbiological,
51 670 chemical and nutritional), either alone or in combination, these being MCDA, risk matrices, stated
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8 671 preferences techniques, and expert synthesis. For microbiological hazards, there is a close relationship
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10 672 between exposure and resulting levels of illness and death, which allows CoI and DALY/HALY
11 673 calculations to be made. With chemical contamination of food, there is no such direct relationship
12 674 between the contamination and resulting diseases/deaths in the population, since effects on human
13 675 health are long-term and, hence, the cause-effect relationship is difficult to establish. Consequently,
14 676 these methods are not often applied to chemical food contamination, although an exception is the
15 677 study by Kemmeren et al. (2006) who calculated DALYs for chemical contaminants, using
16 678 assumptions on the relations between chemical food contamination and disease outcomes. Although
17 679 health effects of nutritional hazards are often evident only in the longer term, recent improved
18 680 availability of insights from long-term epidemiological studies on the cause-relationships between
19 681 nutritional hazard and disease outcomes sometimes allow COI and DALY/HALY be applied to
20 682 nutritional hazards. Risk assessment methodology can be applied to chemical hazards and
21 683 microbiological hazards, when it is known as quantitative microbiological risk assessment (QMRA).
22 684 Although the same procedure is followed, the calculations and the information required are quite
23 685 different. Both RA types aim to calculate human exposure to a particular food safety hazard - the
24 686 chemical contaminant and the pathogen, respectively – through food consumption. The main
25 687 difference is that MRA calculates the pathogenic contamination of food at time of consumption and
26 688 numbers of people getting ill from consuming that food, whereas chemical RA calculate the exposure
27 689 of the contaminant by food at the time of consumption and evaluate if this exposure is below or above
28 690 the Tolerable Daily Intake (ADI), or similar. For ranking several chemical contaminants in food at
29 691 once, methods typically applied are the risk ratio method and the scoring method. These methods
30 692 either multiply or divide a parameter for occurrence of the chemical (e.g. concentration) and the
31 693 severity of the hazard (e.g. TDI).
32 694 MCDA was mostly applied to rank microbiological hazards, but could also be applied for ranking
33 695 chemical hazards, or both. However, when applied to ranking two or even three types of hazards (if
34 696 nutritional hazards are included), great care must be taken in designing the MCDA so that a common
35 697 set of parameters are identified which are relevant to all hazard groups.

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8 698 For some methods, such as risk matrix and risk ratio, essential data needs appear to be smaller than
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10 699 with other methods, like RA, CRA and MCDA. However, it is more that these former methods could
11 700 also be applied when less information is available, although ideally larger amounts would be available.
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13 701 This is in contrast to the latter methods that have a large demand of quantitative data and can only be
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15 702 applied when these data are available. When new, additional data become available, this should be
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17 703 processed by the method selected in order to update risk ranking results. Automatic or easy updating
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19 704 of results is an issue that was hardly touched upon in the risk ranking method application found in
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21 705 literature, but this issue merits further investigation. In addition, automatic or easy updating of results
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23 706 could also be used for the scenario analyses or sensitivity analyses of results. It requires an IT
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25 707 application of data, stored in datasheets or databases, linked to model calculations expressed in scripts.
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27 708 Methods most suitable for such an automatic update are RA, risk ratio, risk scoring, risk matrices,
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29 709 COI, HALY, and MCDA. It is more difficult to apply with CRA, WTP and expert synthesis. For WTP
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31 710 and expert synthesis, the context in which participants make their choices will be altered (e.g. changes
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33 711 in relative prices or perceived risk), and hence primary data will need to be collected again with the
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35 712 method designed to reflect the altered context.
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37 713 Methods that apply quantitative approaches demand more data and result in more precise outcomes
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39 714 with a better description of the uncertainties, assuming that data quality is high. Qualitative methods
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41 715 can be used when data are scarce, e.g., when emerging hazards, such as botanicals, are to be ranked.
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43 716 They also have the advantage of generating rich descriptive material, by which insights into the
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45 717 reasoning behind the opinions (or ranking decisions) of participants can be obtained. In the cases of
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47 718 limited data availability, the appropriate methods are risk matrix, flow charts/decision trees with an
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49 719 emphasis on input from experts, or a ranking based solely on expert synthesis of available quantitative
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51 720 and qualitative information. In the cases of the latter, use qualitative inputs, the outcomes will also be
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53 721 less precise.
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55 722 In general, quantitative methods taking into account uncertainty and variability require more time and
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57 723 resource than qualitative methods. However, most methods that are used for qualitative situations can
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59 724 also be used semi-quantitatively or quantitatively. And in the latter case, they would also require an
60 725 equal amount of time and resource. For instance, risk matrices and expert judgements can be used in a

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8 726 simple application using qualitative input or asking the expert to provide their qualitative opinion,
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10 727 respectively. When performed more quantitatively also expert judgement and risk matrices are also
11 728 resource intensive.

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13 729 In principle, all methods can account for uncertainty and variability in the input data used,
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15 730 acknowledging this information is more precise and quantitatively defined with the quantitative
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17 731 methods. RA and CRA, both of which can accommodate uncertainty and variability in the input data,
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19 732 appear to be very useful methods for providing quantitative results, provided their substantial data
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21 733 requirements are met. . Semi-quantitative and qualitative methods could also allow for inclusion of
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23 734 uncertainty. Two methods do not have the capacity to consider uncertainty in terms of outcomes, these
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25 735 being risk matrix and flow/decision charts.

26 736 Risk ranking can be based on a narrow range of parameters, e.g., measurements of exposure and effect
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28 737 on human health, such as risk ratio or the scoring method, or can include wider issues such as
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30 738 economic impacts and societal preferences. Most methods are demanding of time and other resources,
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32 739 e.g., for primary data collection, although some predefined tools for risk ranking are openly available .
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34 740 MCDA is typically applied when, besides exposure and effect, other metrics need to be considered,
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36 741 such as the consumers' perception of risk associated with different hazards. The strength of this
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38 742 method is in this wider applicability and the involvement of stakeholder groups to assess preference
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40 743 functions and weights. It is often applied in a multi-stakeholder situation. WTP is typically applied
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42 744 when consumer perception on food safety is to be included in the risk ranking.

43 745 The results of risk rankings should be interpreted carefully as relatively small differences in
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45 746 methodology can result in changes in final rankings. There is a need for transparency regarding the
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47 747 method used and its application and adequate explanation so users can understand the rationale which
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49 748 has been used to derive the numbers.

50 749 An important element of all risk ranking activities is communication of the outputs to interested end-
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52 750 users, including the general public. A question arises as to how such communication processes are
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54 751 developed from the outputs of these different risk ranking methodologies in forms which are both
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56 752 understandable and relevant to different interested end-user communities, and there is no comparative
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58 753 analysis currently available. Including risk perceptions may, for example, increase the relevance of the

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8 754 outputs to the general public, but the extent to which such communication is trusted compared to the
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10 755 communication of outputs from risk ranking methodologies where this has not been the case requires
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12 756 further research, as does the development of a more general communication strategy regarding risk
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14 757 ranking practices and allocation of resources to associated risk mitigation activities.

15 758 In conclusion, this study showed there is a wide range of methods that can be used for ranking food
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17 759 related hazards, based on their impact on human health. It has demonstrated that there is no single best
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19 760 risk ranking method. Each of the method categories has its own strengths and weaknesses. The most
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21 761 suitable methods should be selected based on the risk manager's requirements and needs, as well as
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23 762 available resources , the risk ranking task at hand, data availability and the characteristics of the
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25 763 methods. To this end, close communication between risk managers and risk assessors is needed to
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27 764 identify to the most suitable method for risk ranking. Uncertainties associated with data input need to
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29 765 be clearly stated. To date, this is not part of the standard procedure of most methods. This overview is
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31 766 valuable for industrial and governmental risk managers, and risk assessors for selecting the most
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33 767 appropriate methods for risk ranking of food and diet related hazards on the basis of human health
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35 768 impact. The overview will facilitate this decision process and allow for a structured and transparent
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37 769 selection of the most appropriate risk ranking method.

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45 776 colleagues on the study results.

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11 1058 **Figure 1:** Framework for risk ranking of chemicals, adapted from Bu et al. (2013).

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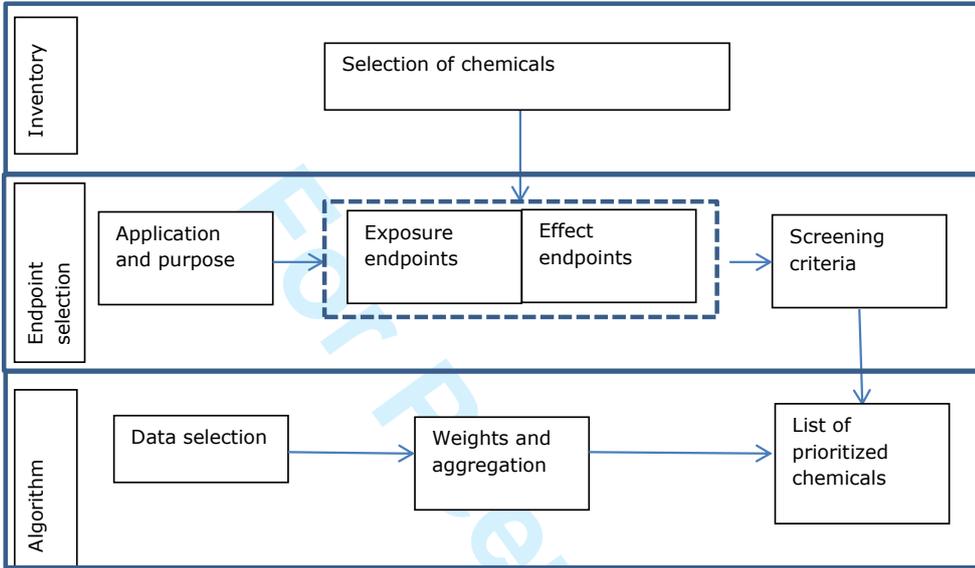
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15 1060 **Figure 2:** Example of Risk matrix

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1062 Figure 1.



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1065 Figure 2

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Severe
Almost certain	M	H	H	E	E
Likely	M	M	H	H	E
Possible	L	M	M	H	E
Unlikely	L	M	M	M	H
Rare	L	L	M	M	H

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1067 Table 1: Results of the literature search in the two-tier approach

Type hazard/field	Tier 1: Title, abstract, keywords			Tier 2: Full text	
	Not relevant	Maybe relevant	Relevant	Not relevant	Relevant
Chemical hazards	5769	79	173	5943	101
Microbiological hazards	2601	74	257	2844	110
Nutritional hazards	979	58	12	1045	4
Health adjusted live years	90	13	9	98	18
Socio-economic methods	3296	47	15	3366	20

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1070 Table 2: Number of references per method categories for risk ranking of the food and/or nutritional
 1071 hazards

Type hazard	Risk assessment	Comparative risk assessment	Ratio	Scoring	Cost of illness	Health Adjusted LY	Stated preference ¹	MCDA ¹	Risk Matrix	Flow chart	Expert synthesis
Chemical	19	0	31 ²	19 ³	1 ²	9 ^{3,4}	1 ²	13	12	13	0
Microbiological	72	0	6 ²	5 ³	9 ²	19 ³	6 ²	4	4	7	14
Nutritional	4	3	1	0	0	1 ⁴	0	1	0	2	0
Other	0	0	0	0	0	0	1	1	0	0	1
Sum	95	3	38	24	10	29	8	19	16	22	15

1072 ¹WTP: Willingness to Pay; HALY; health adjusted live years, MCDA: Multi Criteria Decision

1073 Analyses;

1074 ²One reference described both chemical and microbiological hazards;

1075 ³Three references described both chemical and microbiological hazards;

1076 ⁴One reference described both chemical and nutritional hazards.

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8 1078 **ANNEX 1. Literature search protocol**

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12 1080 a) Search strategy and search strings

13 1081 The search strategy consisted of three major steps, each designed to search titles and subject headings.
14
15 1082 Combinations of search strings were used, starting with a broad screening for methods for risk ranking
16
17 1083 and prioritisation in the field of food related issues (step 1), then narrowing down the methods relating
18
19 1084 to size of anticipated impact on human health (step 2), and finally focusing on chemical hazards,
20
21 1085 biological hazards, nutritional components, or social issues related to food (step 3). The strategy steps
22
23 1086 and final search strings are as follows:

24 1087 **Step 1:** Captured titles/subject headings that studied methods and tools for risk ranking and
25
26 1088 prioritization related to food issues. This step included the following search strings:

27
28 1089 TOPIC = (risk*¹ OR hazard*) AND

29
30 1090 TITLE = (categor* OR rank* OR method* OR nomogram* OR matric* OR decision* OR
31
32 1091 priori* OR analys* OR mc*a OR multi-criteri* OR assessment*) AND

33 1092 TOPIC = (food* OR agri* or agro*OR environ*) AND

34
35 1093
36
37 1094 **Step 2:** Captured titles/subject headings that investigated risk ranking and prioritisation methods on
38
39 1095 the basis of anticipated health impact. This step included the following search terms:

40
41 1096 TOPIC = (disease* OR human health* OR *tox* OR illness* OR cost* OR sever* OR adi*
42
43 1097 OR tidl* OR epidemiol* OR BoD OR wtp OR incidence OR prevalence)

44 1098 TOPIC = ("socio* impact" OR "econ* impact" OR WTP OR cost* OR WTA)

45
46 1099
47
48 1100 **Step 3:** Captured titles/subject headings that investigated specific application fields of biological
49
50 1101 hazards, chemical hazards, nutritional components in food, or social science issues related to food
51
52 1102 hazards, from consumer and governance perspectives. This step included the following search strings:

53 1103 TITLE = (zoonos* OR microb* OR gen* OR pathogen* OR qmra OR "antimicrobial
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55 1104 resistance" OR parasite* OR virus* OR bacteria* OR micro*rgan* OR prion* OR TSE* OR
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57 1105 QRA) AND

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1106 NOT = benefit*

1107 OR:

1108 TITLE = (nano* OR chemic* OR antibiotic* OR dioxin* OR "heavy metal*" OR carc* OR

1109 pesticid* OR "plant protection product*" OR hormon* OR mycotoxin* OR phytotoxin* or

1110 phycotoxin* or marine biotoxin* OR Biocid* OR *contam* OR *pollutant* OR Melamin*

1111 OR Acrylamid* OR PCB* OR Residu* OR Endocr* OR Mutag* OR Botanic* GMO* OR

1112 "Genetic* modif*" OR "Novel protein*" OR Allerg* OR Insecticid* OR Acaricid* OR

1113 Herbicid* OR Fungicid* OR "plant growth regulat*" OR POP OR POPs OR Persistent* OR

1114 *accumul*) AND

1115 NOT = benefit*

1116 OR

1117 TITLE = (*nutri* OR *diet* OR bioavail* OR *supplement* OR "Novel protein*" OR

1118 Fortification* OR "Novel food*" OR Allerg*) AND

1119 NOT (toxic* OR microbial* OR chemic* OR socio* OR benefit*)

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1121 DALY/QALY concept:

1122 TOPIC = (daly* OR qaly* OR haly* OR HRQL* OR HALE) AND

1123 NOT = benefit*

1124

1125 OR

1126 TOPIC = ("focus group*" OR survey* OR interview* OR public* OR "expert analys*" OR

1127 *attitud* OR *percep* OR Willingness* OR *Soci* OR Determ* OR Cultur* OR Tradition*

1128 OR Typic* OR Consumer* OR Ethic* OR accept* or opinion* or view* or behaviour* or

1129 behavior* or employ* or communicat* or dialog* or engage* or particip* or gover* or legal*

1130 or law* or regul*) AND

1131 NOT: religious* or halal* OR benefit*

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1133 b) Evaluation criteria

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8 1134 The references judged to be relevant for the study objectives were evaluated for eligibility and quality
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10 1135 of the described research. References were included when:
- 11 1136 1. Reference was relevant for the objective of the literature review;
 - 13 1137 ○ References discussing prioritisation/ranking methods for human health risks and/or,
 - 15 1138 ○ References describing risk prioritization/ranking methods applied for
16 1139 environmental/ecological risks and/or,
 - 18 1140 ○ References to risk prioritization, risk analysis, risk assessment methods and/or risk
20 1141 modelling included in abstract and/or,
 - 22 1142 ○ Any relevance of the work for application to human health, including references on
24 1143 drinking water and/or,
 - 26 1144 ○ Abstract indicates socio-economic research methodology is employed.
 - 28 1145 2. Reference came from international peer-reviewed journals;
 - 30 1146 3. Methods in the reference were well described, (semi-)quantitative or qualitative, user-friendly,
31 1147 transparent, structured, and objective;
 - 33 1148 4. Methods in the reference were applicable in wider decision making schemes/frameworks;
 - 35 1149 5. In case of reports, they should originate from well-known, highly-respected governmental
36 1150 bodies or research organisations.
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39 1151
40 1152 Criteria for excluding references were:
- 42 1153 - References discussing only parts of a method (only exposure or only human health effects),
44 1154 such as references dealing with presence of chemical hazards, analytical methods, and/or
46 1155 references about toxicity studies. These are all parts of a risk assessment and/or,
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 - 48 1156 - References addressing non-human related aquaculture and non-human related animal health.
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1157 Table 3. Characteristics of risk ranking methods related to food safety

Characteristic	Risk Assessment	Comparative Risk Assessment	Ratio (Exposure/Effect)	Scoring method	Cost of Illness	HALY ¹	WTP ¹	MCDA ¹	Risk Matrix	Flow charts /Decision trees	Expert Synthesis
Amount of resources (time, money)	High	High	Moderate	Moderate	Moderate	Moderate	High	High	Low	Low	Moderate /Low
Level of output	Quantitative	Quantitative	Semi-quantitative	Semi-quantitative	(Semi-) quantitative	(Semi-) quantitative	(Semi-) quantitative	Semi-quantitative	Qualitative/semi-quantitative	Qualitative	Qualitative
Easy to explain to stakeholders (laymen)?	No	No	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes
Inclusion stakeholder perception	Not possible	Not possible	Not possible	Possible	Not possible	Not possible	Possible	Possible	Not possible	Possible	Possible
Inclusion uncertainty	Possible	Possible	Possible	Possible	Possible	Possible	Possible	Possible	Not possible	Not possible	Possible
Inclusion weights for the risk ranking criteria	Not possible	Not possible	Not possible	Possible	Not possible	Not possible	Not possible	Possible	Not possible	Not possible	Possible
Inclusion human incidences	Possible	Possible	Not possible	Not possible	Possible	Possible	Possible	Possible	Not possible	Possible	Possible
Inclusion economic impact	Not possible	Not possible	Not possible	Not possible	Possible	Not possible	Possible	Possible	Not possible	Possible	Possible
Common method of communication (in addition to reports)	Graphs/Tables	Graphs/Tables	Tables	Tables	Graphs/Tables	Graphs/Tables	Graphs/Tables	Graphs/Tables	Graphs	Decision Tree	Tables
Essential data needed											
Human incidence data needed?	No	Yes	No	No	Yes	Yes	Yes	No	No	No	No
Dose-response data needed?	Yes	Yes	No	No	No	No	No	No	No	No	No
Occurrence data (concentration, prevalence, dose) needed?	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
Food consumption data needed?	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
Growth models needed (only applicable for microbiological hazards)?	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No

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Toxicological reference values (ADI, TDI etc) needed (only applicable for chemical hazards)?	Yes	Yes	Yes	Yes	No						
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1158 ¹WTP: Willingness to Pay; HALY; health adjusted live years, MCDA: Multi Criteria Decision Analysis

For Peer Review Only

Methods for risk ranking food safety and dietary hazards

RESEARCH PAPER

Critical review of methods for risk ranking of food related hazards, based on risks for human health

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ABSTRACT

This study aimed to critically review methods for ranking risks related to food safety and dietary hazards on the basis of their anticipated human health impacts. A ~~systematic~~ literature review was performed to identify and characterize methods for risk ranking from the fields of food, environmental science and socio-economic sciences. The review used a predefined search protocol, and covered the bibliographic databases Scopus, CAB Abstracts, Web of Sciences, and PubMed over the period 1993-2013.

All references deemed relevant, on the basis of a predefined evaluation criteria, were included in the review, and the risk ranking method characterized. The methods were then clustered – based on their characteristics - into eleven method categories. These categories included: risk assessment, comparative risk assessment, risk ratio method, scoring method, cost of illness, health adjusted life years, multi-criteria decision analysis, risk matrix, flow charts/decision trees, stated preference techniques and expert synthesis. Method categories were described by their characteristics, weaknesses and strengths, data resources, and fields of applications.

It was concluded there is no single best method for risk ranking. The method to be used should be selected on the basis of risk manager/assessor requirements, data availability, and the characteristics of the method. Recommendations for future use and application are provided.

KEY-WORDS

Risk prioritization, risk ranking, food safety, nutritional hazards, health impact.

1. INTRODUCTION

Ranking of health risks related to food safety and nutrition is generally recognised as the basis for risk-based priority setting and resource allocation. It permits governmental and regulatory organisations to allocate their resources efficiently to the most significant public health problems (Van Kreijl et al., 2006). Within the area of food, risk is defined as the analysis and prioritization of the combined probability of food contamination, consumer exposure and the size of the anticipated public health impact of specific chemical, microbiological and/or nutritional hazards related to food. It is the combination of the *probability that a hazard may occur* in a food product and the *effect of exposure to the hazard on human health* (Codex Alimentarius 2001). Risk ranking has been applied to food safety monitoring programs and has shown to increase the efficiency of monitoring and to decrease inspection costs, both in practice and from theoretical calculations (Baptista et al., 2012; Presi et al., 2008; Reist et al., 2012).

To date, various risk ranking methods are available that prioritise food safety risks (Van Asselt et al., 2012). Methods vary from qualitative, through semi-quantitative, to quantitative methods (Cope et al., 2010; Van Asselt et al., 2012). ~~Examples of tools that apply quantitative methods are the swift QMRA tool (Evers and Chardon, 2010) and iRISK, which is a comparative risk assessment system for evaluating and ranking food hazard pairs (Chen et al., 2013, see <http://www.foodrisk.org>).~~ ~~As quantitative methods can be very elaborate, semi-quantitative tools such as Risk Ranger (Ross and Sumner, 2002) have also been developed (Food Safety Centre, 2010).~~ Most methods are based on the ‘technical’ concept of risk being a function of presence of the hazard and severity of its impact on human health. However, some methods also involve other metrics, which may be considered in decision making, e.g., consumer perceptions of risk. In order to determine which methods are most suitable for ranking food related risks, it is important to follow a structured, objective and transparent approach to identifying and evaluating the available methods (van Asselt et al., 2013).

The aim of the current study was to review available methods for ranking risks associated with food on the basis of anticipated health impact, to characterize the methods and to provide recommendations for their use.

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10 64 **2. MATERIAL AND METHODS**

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13 66 **2.1 Protocol for literature review**

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15 67 A literature review was conducted which aimed to identify risk ranking methodologies that can be
16 68 used to prioritize food related hazards, on the basis of the size of anticipated health impact. Hazards
17 69 are defined as those agents that can be present in food and can negatively affect human health (Codex
20 70 Alimentarius, 2001). Hazards included in this study were nutritional, chemical and microbiological
22 71 hazards. The review covered methods from the fields of natural/life (food) science, socio-economic
24 72 sciences and food safety governance, published during the period 1993-2013. Risk ranking methods
26 73 from fields outside food science (i.e. environmental sciences and socio-economic methods) were also
28 74 included to evaluate their appropriateness for application in food science. The literature review
30 75 followed the principles of a systematic literature review as described by EFSA (2010). A protocol for
31 76 the structured literature review was defined *a priori*, including search strings and criteria for
33 77 evaluation of the literature references (Annex 1).

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37 79 **2.2 Literature review**

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41 81 Review methodology

- 42 82 a. Scientific articles were identified using the following bibliographic databases: Web of Science,
44 83 Scopus, PubMed, and CAB Abstracts. In addition, the general search engine Google was used to
46 84 search for reports, (the 'grey literature'), from relevant international and national organisations,
48 85 authorities, and agencies (e.g., EFSA, EMA, WHO/FAO, FDA, Health Canada, OECD). The
49 86 literature search focused on papers and reports published in English.
- 51 87 b. The set of search strings was applied leading to an initial set of search results. All retrieved
53 88 references were stored in an Endnote database. Duplicates, a result of using four different
55 89 bibliographic databases, were removed.

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8 90 c. The references resulting from the initial set of search results were screened for their relevance to
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10 91 the study objectives by applying the evaluation criteria. A two-tier approach was used. In tier 1,
11 92 the applicability of each reference to the review objective was determined by examining the title,
12 93 abstracts and key-words of each reference. Based on this evaluation, the references were allocated
13 94 to one of three categories and placed in the corresponding category of the Endnote database:
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17 95 - *Relevant for this study*: the reference was included;
18
19 96 - *Possibly relevant for this study*: uncertain if the reference was relevant for the study;
20
21 97 - *Not relevant for this study*: the reference was determined to be out of scope.

22 98 An inter-observer check was conducted with a randomly selected subset (10%) of both selected
23
24 99 and excluded references.

- 25
26 100 d. In tier 2, the full text of the references that were in the *Relevant* and *Possibly relevant* groups of
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28 101 the Endnote database were retrieved. By reading the full texts, the papers/reports were evaluated
29
30 102 for their relevance to the field of interest and their quality using the evaluation criteria. When
31
32 103 deemed relevant, the reference was retained or moved to the group *Relevant* in the Endnote
33
34 104 database. When deemed not relevant, the reference was moved to the group *Not relevant* in the
35
36 105 Endnote database. Also at this stage, an inter-observer check was conducted; certain (randomly
37
38 106 chosen) literature references were evaluated by two experts from of the team (from different
39
40 107 disciplines) in order to gain insights into the variation between the evaluation results of two
41
42 108 different experts.
43
44 109 e. Citations used in the reports/references of the final Endnote database were screened for additional
45
46 110 relevant references, published after 1993 (snowball citation), and steps c) and d) were applied to
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48 111 them.

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50 113 Evaluation of references

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52 114 For each reference stored in the *Relevant* category of the Endnote database, the risk ranking method
53
54 115 and its characteristics were evaluated in depth. A summary of the information obtained was stored in
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56 116 an excel sheet, using a unique row for each reference. The format of the excel sheet was defined
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58 117 beforehand, starting from the template developed by EFSA's BIOHAZ panel (EFSA, 2012b), but with

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8 118 some modification to increase relevance to the objectives of the current study. Separate columns were
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10 119 utilised for information about the reference (author names, title, abstract, journal, volume and page
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12 120 numbers), and for storing the results from the critical evaluation of the risk ranking methods including:
13
14 121 the type of tool (short description); field of application (microbiological, chemical, and/or nutritional
15
16 122 hazards); what was ranked (e.g., specific food products); specific application area (e.g., pesticides);
17
18 123 metrics, i.e., the type of method, with different sub-columns for each method category; model
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20 124 structure (quantitative, semi-quantitative or qualitative); data requirements that describe the model
21
22 125 variables (e.g., human population data, or microbial numbers); method of data collection, describing
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24 126 how the necessary data were collected and which data sources were used, and finally data integration,
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26 127 describing how data were integrated in the application described in the reference. Based on this
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28 128 evaluation, the references and the evaluated methods were categorised into different groups of
29
30 129 methods. The method categories were then described according to the following characteristics: scope,
31
32 130 application area, approach, strengths and weaknesses, and perspective for use by-by risk
33
34 131 managersstakeholders. At this stage, reviews on risk ranking methods and other relevant literature
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36 132 were also consulted..
37
38 133

39 135 **3. RESULTS ~~AND DISCUSSION~~**

40 136 41 137 **3.1 Literature search**

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43 138 At tier 1, application of the search strings and removal of duplicates led to the retrieval of the
44
45 139 following numbers of references (Table 1): 6021 for chemical/toxicological hazards; 2932 for
46
47 140 microbiological hazards; 1049 for nutritional hazards; 112 references using health adjusted live years
48
49 141 method; and 3358 references using socio-economic methodology. The latter two method groups were
50
51 142 considered since they could potentially include each of the three types of hazards (microbiological,
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53 143 chemical and/or nutritional hazards). The total numbers of references appearing in tier 2 are somewhat
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55 144 higher than in tier 1 due to snowballing citations. In total 253 references were judged to be relevant.
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57 145

146 3.2 Description of risk ranking methods

147 Based on the evaluation of the methods described in the relevant references, the risk ranking methods
148 were classified, according to methodology, into the following categories: 1) Risk Assessment (RA), 2)
149 Comparative risk assessment (CRA), 3) Risk ratio method, 4) Scoring method, 5) Risk matrix, 6) Flow
150 charts (including decision trees and influence diagrams), 7) Cost of illness (CoI), 8) Health adjusted
151 life years (HALY), 9) Multi criteria decision analysis (MCDA), 10) Stated preference methods, and
152 11) Expert judgement. Table 2 shows the numbers of references that presented a particular method
153 category, per type of hazard. All methods included both presence of the hazard and its
154 severityexposure and effect. Method categories differed in , although the way in which these two
155 factors were evaluated and combined to come to an estimate of the riskcovered varied between the
156 method categories. In some instances, a combination of methods was applied, in which case the study
157 was classified to its main category.

158 RA was by far the most frequently applied method. This method was applied to both chemical
159 and microbiological hazards. For each of the chemical and microbiological hazards, about one third of
160 all tier 1 references described the application of a RA to a particular hazard. However, as the
161 procedure for each of the chemical and microbiological RA is comparable, only references describing
162 guidelines for performing a RA were included. Risk ratio, scoring, risk matrices and flow charts were
163 mostly applied to chemical hazards, whereas CoI, HALY, and expert judgments were mostly used for
164 ranking microbiological hazards (Table 2). Ranking methods for nutritional hazards were fewer, and
165 were mostly based on RA, CRA and expert judgement (Table 2). CRA, CoI, and stated preferences
166 were the methods that were applied least frequently, with CRA used in three studies about nutritional
167 hazards, and the latter two methods primarily applied to microbiological hazards. A few studies have
168 considered both chemical and microbiological hazards in their ranking, applying methods for CoI and
169 HALY. Summaries of each method and characteristics are presented in the following sections and in
170 Table 3.

172 3.2.1. Risk Assessment

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8 173 Scope: A RA for a chemical or microbiological hazard aims to estimate the risk for human health
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10 174 associated with the presence of the hazard in one or more food products, and total food consumption.
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12 175 Numerous risk assessments have been applied to chemical and microbiological hazards in food. WHO
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14 176 (WHO, 2009) and Codex Alimentarius (~~2014~~~~2012~~) have provided guidelines regarding the principles
15
16 177 and methods for the risk assessment of chemical contaminants and pathogens in foods. Although the
17
18 178 application of the RA methodology is tailored to the hazard type, the principles for performing a risk
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20 179 assessment for both types of hazards are identical, consisting of the following four steps: hazard
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22 180 identification, exposure assessment, hazard characterisation, and risk characterization.

23 181 Application area: Risk assessment is usually applied for one identified (chemical or microbiological)
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25 182 hazard occurring in a specific food commodity and for a predefined population, with the purpose of
26
27 183 characterizing- the associated health risk. Apart from this, an important reason for conducting a RA is
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29 184 to evaluate the impact of control measures to reduce the risk. If the results of different RA are
30
31 185 compared (e.g. for different hazards or different foods), the RA can be used for risk ranking.

32 186 Approach: Various RA approaches for chemical and microbiological hazards in food were identified,
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34 187 applying different combinations of deterministic, probabilistic (or stochastic), qualitative, semi-
35
36 188 quantitative, and quantitative modelling. Furthermore, different approaches were used for the exposure
37
38 189 assessment and the hazard characterization steps. EFSA (2011) published an overview of procedures
39
40 190 for current RA methods for dietary exposure of different chemical substances. The need for
41
42 191 development of harmonized approaches, and future exploration of cumulative exposure assessments,
43
44 192 is identified. In 2012, EFSA published its experiences gained with Quantitative Microbiological Risk
45
46 193 Assessment (QMRA) studies (EFSA, 2012a).

47 194 Strengths and weaknesses: In RA, all available scientific and technical information and data, as well as
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49 195 variability and uncertainties are systematically organized and analysed. It is a well-structured method,
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51 196 providing insights into what is known and what is not known. In particular, RA offers the opportunity
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53 197 to address uncertainties in a transparent way, e.g., *via* sensitivity analyses and/or modelling and
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55 198 simulation runs. It could be the most precise method to estimate risks, including the relevant
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57 199 uncertainties. However, a RA for one chemical or microbiological hazard usually requires a lot of
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59 200 time, data and knowledge. Ranking risks related to various hazards in food using outcomes of

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8 201 individual RAs will take even more resources and RAs are often hampered by a lack of quantitative
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10 202 data. Lack of data, selection of models to fit to the data, and assumptions that need to be made give
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12 203 rise to uncertainties in the outcomes. Recently, several tools for relative risk assessment for pathogens
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14 204 of pathogen-food combinations have been published. Examples of such tools applying quantitative
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16 205 methods are the swift QMRA tool (Evers and Chardon, 2010) and iRISK, which is a relative risk
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18 206 assessment system for evaluating and ranking food-hazard pairs (Chen et al. 2013, see [https://irisk.foodrisk.org/](http://</u>
19
20 207 <u><a href=)). An example of a semi-quantitative approach is Risk Ranger (Ross and
21
22 208 Sumner, 2002) developed by Food Safety Centre (2010).
23
24 209 Perspective for use by risk manager: Applied optimally, RA should disseminate key information
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26 210 regarding risk from exposure to food hazards to policy makers, decision makers and the public. RA
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28 211 are very useful for providing insights into gaps in knowledge and issues associated with high levels of
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30 212 uncertainty. However, they may not be suitable for risk ranking given the large amounts of data,
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32 213 knowledge and resources needed.

33 214 34 215 3.2.2. Comparative risk assessment

35 216 Scope: A Comparative Risk Assessment (CRA) analysis can estimate the number of deaths that would
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37 217 be prevented in a given period if current distributions of risk factor exposure were changed to a
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39 218 hypothetical alternative distribution (Danaei et al., 2009; Micha et al., 2012). In these papers, CRA is
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41 219 restricted to comparisons of deaths and it is, therefore, not comparable to a risk assessment or a
42
43 220 relative risk assessment.

44 221 Application area: Three applications of CRA have been found; each of them studied the impact of
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46 222 dietary factors on disease mortality. Danaei et al. (2009) performed a CRA analysis for establishing
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48 223 the preventable causes of death associated with dietary, lifestyle and metabolic risk factors in the
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50 224 United States. Micha et al. (2012) used a CRA framework to develop methods for assessing the global
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52 225 impact of specific dietary factors on chronic disease mortality. Lim and co-workers (2012)
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54 226 investigated burden of disease and injury attributable to 67 risk factors (including chemical hazards
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56 227 and nutritional imbalances) in 21 regions through application of a systematic analysis for the Global

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8 228 Burden of Disease Study 2010. Although a CRA analysis as described below was not performed by
9 229 Lim et al. (2012), several elements of a CRA analysis were included.

10 230 Approach: A CRA analysis is measured in population attributable fractions (PAFs), which describe the
11 231 total effects of a risk factor (direct/indirect) by reflecting the proportional reduction in deaths for each
12 232 disease causally associated with the exposure that would occur if the usual exposure distribution had
13 233 been reduced to the optimal minimum-risk exposure distribution. Input needed to determine the PAF
14 234 include: a) effect size (relative risk estimate) of the causal diet-disease relationship, b) optimal or
15 235 theoretical minimum-risk exposure distribution, c) dietary risk factor exposure distribution in the
16 236 population and, d) total number of disease-specific deaths (plus non-fatal events, when available) in
17 237 the population. Data sources for obtaining these inputs include epidemiological studies, systematic
18 238 reviews, meta-analysis, nationally representative nutrition surveys and mortality databases.

19 239 Strengths and weaknesses: A CRA analysis is a systematic assessment of unbiased data collected in
20 240 national and international surveys as well as the peer reviewed literature. It allows for consistent,
21 241 comparable and quantitative assessment of the global impact of risk factors on disease by sex- and
22 242 age-specific groups. A CRA analysis requires knowledge and resources (manpower, money, data),
23 243 which makes it expensive to perform. Unbiased data are also needed, e.g., to establish exposure
24 244 distributions or causal diet-disease relationships, which may often not be easily accessible or available.
25 245 The weights of different diseases are not considered. Uncertainties associated with a CRA analysis can
26 246 be high because of data limitations.

27
28 247 Perspectives for use by risk managerstakeholders: A CRA analysis offers a global assessment of the
29 248 impact of dietary factors on disease mortality, which is very valuable for priority setting and policy
30 249 making. However, with large and overlapping uncertainty ranges for the different risk factors, ranking
31 250 of modifiable dietary risk factors may be difficult.

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52 252 3.2.3. Risk ratio method
53 253 Scope: Risk ratios or quotients ~~refer to a~~ quantitative method in which derived by dividing estimates
54 254 of exposure are divided by estimates of effect. For this purpose, data are needed regarding the amounts
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8 255 of the hazard consumed (either the dose or the concentration) as well as a measure for the effect of the
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10 256 hazards that are studied.

11 257 Application: The risk ratio method has usually been applied to rapidly screen the risk of a range of
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13 258 chemical compounds in order to rank them. Most studies applied the method to rank pesticides,
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15 259 although five studies focused on microbiological hazards, and one study applied the method to rank
16
17 260 both chemical and microbiological hazards.

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19 261 Approach: For chemical contaminants, some references derive a Hazard Index, in which the Estimated
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21 262 Daily Intake (EDI) is divided by the Acceptable Daily Intake (ADI), Tolerable Daily Intake (TDI) or
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23 263 the acute Reference Dose (RfD) (Calliera et al., 2006; Oldenkamp et al., 2013; Sinclair et al., 2006).
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25 264 The Margin of Exposure (MoE) approach is another method in which exposure and effect are
26
27 265 compared by dividing the NOAEL (No Observed Adverse Effect Level) or the BMD (Bench Mark
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29 266 Dose) by the EDI (Bang et al., 2012; Madsen et al., 2009; Rietjens et al., 2008). The Hazard Index
30
31 267 should be as low as possible, whereas the MoE should be as large as possible to obtain a low risk for
32
33 268 human health. In general, the risk of pesticide residues for human health is ranked using the Hazard
34
35 269 Index (e.g., Labite and Cummins, 2012; Sinclair et al., 2006; Travisi et al., 2006; Whiteside et al.,
36
37 270 2008), whereas the risk of carcinogenic compounds is primarily ranked using MoE (Dybing et al.,
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39 271 2008; Lachenmeier et al., 2012). Applications of the method to microbiological hazards used different
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41 272 criteria, such as costs and effective dose.

42
43 273 Strengths and weaknesses: This method is easy to understand, and can be applied once concentration
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45 274 data and toxicological reference values are available; it only needs an estimate for both amounts of the
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47 275 hazardous material consumed and the effect of the hazard on human health. For emerging chemical
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49 276 hazards, e.g., nanomaterials, toxicological reference values are usually not available. ~~Furthermore,~~
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51 277 ~~concentration data are also not always available. It may thus be difficult to rank all hazards of interest~~
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53 278 ~~due to data limitations.~~

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55 279 Perspectives for use by risk manager stakeholders: The method can give a quick answer on the risk of
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57 280 food safety hazards for human health, and can be applied to both chemical and microbiological
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59 281 hazards.
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3.2.4. Scoring methods

Scope: This method is based on semi-quantitative scoring of both exposure and effect of the hazard on human health, followed by their multiplication (or – in one reference - addition).

Application: Scoring methods provide a simple risk ranking method to characterize chemical hazards for subsequent categorization into particular groups (Aylward et al., 2013; Bietlot and Kolakowski, 2012; Bu et al., 2013; Greim and Reuter, 2001; Taxell et al., 2013; van Asselt et al., 2013).

Approach: When a scoring method is applied, both exposure and severity (or effect) endpoints are considered. However, endpoints for exposure and effect can vary. Various endpoints have been used to estimate exposure, such as chemical transformation properties (degradability, half-life), mobility/distribution (such as bioaccumulation factors (BAF) or bioconcentration factors (BCF)), release, frequency of detection, and dose administered/concentrations. There is currently no scientific consensus on which endpoints to include and how to set criteria for classifying these endpoints. Consequently, selection of appropriate endpoints for a specific study is one of the steps in ranking risks according to a scoring method. Examples of endpoints for effect on human health might include acute toxicity, carcinogenicity, or reproductive toxicity, and can be based on LD50, MOAEL, BMDL10 etc. Once criteria are set, endpoints are classified semi-quantitatively, e.g., using scores from 1 to 3 or from 1 to 5, as applied in, [for example e.g., \(Penrose et al., 1994\)](#).

After this classification system for endpoints has been established, data sources need to be found in order to assign scores for exposure and effect. These sources can be based on literature, available data and/or expert opinion. Scores subsequently need to be aggregated, which is mainly done by multiplying exposure and effect (see, e.g., Gamo et al., 2003; Juraske et al., 2007; van Asselt et al., 2013), although one study added the scores (Penrose et al., 1994). Some references also employ a weighing system to weigh the various endpoints included in the assessment (Dabrowski et al., 2014; Juraske et al., 2007; Penrose et al., 1994; Valcke et al., 2005). A general framework for risk ranking that includes the choice of endpoints, weighing endpoints and aggregating the scores into a final risk score is depicted in Figure 1.

Strengths and weaknesses: This semi-quantitative method is easy to conduct once scores have been assigned to the model variables. Furthermore, it allows the inclusion of stakeholder perceptions in

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8 311 | assigning the scorings and the importance (to each stakeholder) of each model variable is reflected by
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10 312 | the weighting allocated to it. The assigned weights should then be clearly documented to guarantee a
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12 313 | transparent approach.

13 314 | Perspectives for use by risk managerstakeholders: Stakeholders can use this method to obtain a clear
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15 315 | overview of prioritized risks in relation to food safety hazards. The method has been used as input to
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17 316 | the establishment of national monitoring programmes (VRC, 2010).

18 317 | 19 318 | 3.2.5. Risk matrices

20 319 | Scope: Just like the scoring methods, risk matrices also make use of scoring both exposure and effect
21
22 320 | endpoints. The difference between scoring methods and risk matrices is that, in the latter, the exposure
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24 321 | and effect endpoints are not aggregated by multiplication or addition, but are depicted in a risk ranking
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26 322 | matrix with effect on the one axis and exposure on the other.

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28 323 | Application: This method is usually applied to chemical or microbiological hazards for which limited
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30 324 | quantitative data are available. This method has, for example, been applied for ranking the risks of
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32 325 | nanomaterials (O'Brien and Cummins, 2011; Sorensen et al., 2010; Zalk et al., 2009).

33 326 | Approach: Both the likelihood of occurrence and the consequences of the hazard for human health are
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35 327 | scored into one of several classes; see Figure 2 for an example. Classes that could be used for
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37 328 | likelihood of occurrence are: almost certain, likely, possible, unlikely and rare. Classes that could be
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39 329 | used for the consequences are: insignificant, minor, moderate, major and severe. The division into
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41 330 | these classes is subjective. Then, risk classes are assigned to the combinations of Likelihood and
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43 331 | Consequences, e.g., being L (low), M (moderate), H (high), and E (extreme), as shown in Figure 2.
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45 332 | Risk classification may also be based on scores. Zalk et al. (2009), for example, classified
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47 333 | nanomaterials based on scores for probability and severity, and the results were depicted in a risk
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49 334 | matrix. The results can also be visualized using spider web plots, as conducted by, (e.g.), Ranke and
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51 335 | Jastorff (2000), who classified various endpoints using scores from 1-4, and compared plots for the
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53 336 | various compounds to obtain an indication of the most risky ones.

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55 337 | Strengths and weaknesses: The risk matrix method is qualitative or semi-quantitative, and thus less
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57 338 | accurate than methods based on concentration data and dose-response relationships or toxicological
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8 339 reference values. It provides a visualisation for both presence of the hazard and its effects, giving
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10 340 direct insights into the way these two elements contribute to the overall risk of a hazard. For example,
11 341 a hazard may present a high risk due to a high exposure, although its severity is low. Alternatively,
12 342 due to its high toxicity, it may present a high risk rank despite low exposure. Matrices will give more
13 343 information to the risk manager compared to other methods that produce a list of hazards according to
14 344 the overall risk alone. However, the division between different categories for presence of the hazard
15 345 (e.g. low, medium high occurrence) and its effects (e.g. low, medium, high toxicity) is subjective and,
16 346 thus, other results are obtained when with other divisions.

17 347 Perspectives for use by risk manager: In case stakeholders prefer a graphical representation of the
18 348 risks, this method can be used to visualize both the effect and the exposure of a hazard. This facilitates
19 349 discussions amongst stakeholders regarding the risks of various hazards.

30 351 3.2.6. Flow charts

31 352 Scope: Flow charts or decision trees are based on a set of clearly defined questions or criteria. By
32 353 following these, , the hazards can be classified into different categories (e.g. high, medium or low)
33 354 with respect to their risk for human health.

34 355 Application: Flow charts or decision trees can be used for various purposes. In general these methods
35 356 are used to obtain a qualitative indication about the risks associated with hazards. Haase et al. (2012),
36 357 for example, established a decision tree for nanoparticles to determine whether a full risk assessment is
37 358 required or not. EFSA described guidelines for classifying chemical hazards as negligible, low,
38 359 medium, and high risks (EFSA, 2012c, 2012d).

39 360 Approach: A flow chart is generally based on several questions that need to be answered in order to
40 361 arrive at a certain risk class. Questions can be based on the likelihood that specific chemicals or
41 362 microbiological hazards are present in the study object; evidence of occurrence or incorrect practice in
42 363 the food chain, the toxicological profile, and the outcome of national monitoring programmes (EFSA,
43 364 2012c, 2012d). Eisenberg and McKone (1998) used a Classification and Regression Tree Algorithm
44 365 (CART) to specify the chemical and environmental properties and Monte Carlo simulations to
45 366 estimate human exposure. Schmidt et al. (2011) utilized a decision support system (DSS) to rank

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8 367 genetically modified organisms (GMOs), based on a decision tree and rules, indicators and baselines,
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10 368 and thresholds (such as the LD50) (Schmidt et al., 2011). DSS may also be combined with multi-
11 369 criteria decision analysis (MCDA). Critto (2007), for example, utilised a DSS system to evaluate
12 370 ecological observations and ecotoxicological tests for contaminated sites and then incorporated
13 371 MCDA and expert judgments into the ranking. This approach might also be used for ranking food
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15 372 safety risks.

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17 373 Strengths and weaknesses: Flow charts/decision trees present a straightforward method with clear
18 374 questions for which only qualitative information is needed, although quantitative information can be
19 375 used where available. The method can, thus, be used for a quick screening of food safety hazards, in
20 376 order that the most relevant ones may subsequently be investigated in more detail. However, this
21 377 method strongly depends on expert input and it is, therefore, essential to perform a rigorous expert
22 378 elicitation study. Furthermore, this type of method is vulnerable to being less transparent than other
23 379 methods, as it is not always clear why hazards end up being classified as a high, medium or low risk.
24 380 Therefore, for each hazard classified based on a decision tree or flow chart, the underlying reasons for
25 381 the answers should be clearly documented in order to obtain a transparent classification.

26 382 Perspectives for use by risk manager: It is important to set up the right questions for inclusion in a
27 383 flow chart/decision tree based on expert judgment and scientific evidence, which may be challenging
28 384 to achieve. However, once a decision tree has been drafted, it is easily applicable for stakeholders to
29 385 classify hazards into high, medium and low risks.

3.2.57. Cost of Illness method

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31 388 Scope: The underlying research objective of the Cost of Illness (CoI) approach is distinct from those
32 389 of the methodologies described so far. CoI studies acquire data for conducting economic analysis in
33 390 order to obtain a ranking in terms of how society might allocates scarce resources when addressing
34 391 food-related hazards. The procedure involves ~~methodology implies~~ calculating the directs costs to
35 392 society related to disease and death ~~in society~~ due to chemical, microbial and/or nutritional hazards. It
36 393 can be applied wherever there are quantitative data relating to the impact of disease (severity and

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8 394 duration; mortality) and sufficient cost data for calculating resultant treatment costs and loss of
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10 395 income. Subject to data availability, it is possible to compare large numbers of food risks.

11 396 Application area: This approach can be applied for comparing diseases (Gadiel, 2010), for food-
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13 397 disease combinations (Batz et al., 2011), and for supply chain analysis of a single food-disease
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15 398 combination (Miller et al., 2005).

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17 399 Approach: The starting point of this quantitative method is the construction of a separate disease
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19 400 outcome tree (or equivalent) for each illness under consideration. This will show the numbers (and
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21 401 proportions) of the affected population who experiences each type of impact, defined as the disease
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23 402 severity class. A critical point is whether it is restricted to acute effects, or whether long-term effects
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25 403 (sequelae and deaths) are also included. This will be particularly important for diseases for which
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27 404 some affected individuals will experience life-long disease, or where medical problems may be latent
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29 405 for a period (e.g., toxoplasmosis).

30 406 If possible, the disease outcome tree is populated directly from existing data sources. However, data
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32 407 for disease incidence and attribution to a specific food source is often incomplete. The problems with
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34 408 inadequate or missing data are sometimes overcome by expert elicitation of (ranges of) parameter
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36 409 values (e.g., Batz et al., 2012; Golan et al., 2005). To address uncertainty caused by inadequate data,
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38 410 sensitivity analysis (e.g., Batz et al., 2011) or frequency distributions can be used in Monte Carlo or
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40 411 stochastic simulation models (Lake et al., 2010; Kemmeren et al., 2006). The costs incurred at each
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42 412 state are calculated, often including the categories of direct health costs, indirect health costs, and
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44 413 indirect non-health costs.

45 414 CoI studies generally make use of discounting by which the value of earnings and payments incurred
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47 415 in the future are expressed in terms of their present value. They are expressed as a given amount of
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49 416 money invested today at a given interest rate (or discount rate) (Crutchfield et al., 1999). By definition,
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51 417 discounting does not apply to the costs of health effects whose duration is shorter than one year,
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53 418 whereas other end-points, such as life-long disabilities, are strongly affected by discounting. Hence,
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55 419 the effect of discounting will differ per hazard (Kemmeren et al., 2006) and the rate of interest
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57 420 selected.

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8 421 Strengths and weaknesses: The CoI method employs readily available and reliable data (Buzby et al.,
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10 422 1996) and the calculations are transparent and relatively simple. The same disease incidence data are
11 423 used in HALY calculations so it is relatively efficient to produce both sets of rankings at the same time
12 424 and they are, to some extent, complementary. A combined risk ranking can also be produced. A CoI
13 425 ranking diverges from most measures of disease severity or social welfare (Golan et al., 2005) because
14 426 CoI estimates are restricted to market goods. Therefore, apart from medical costs, the measures
15 427 excludes non-workers, and do not address perceived quality of life including factors such as pain and
16 428 stress (Golan et al., 2005). A further important weakness relates to the lack of accurate public health
17 429 and attribution data, which is the biggest cause of uncertainty in CoI estimates. The results are
18 430 dependent on the assumptions made *inter alia* about medical outcomes and the prevailing labour
19 431 market.

20 432 Perspectives for use by risk managerstake holders: CoI is a well-tried technique with well-understood
21 433 limitations relating to missing data, and failure of the approach to adequately include non-working
22 434 members of society and quality of life impacts. Large numbers of risks can be ranked. The process
23 435 appears highly transparent, but it should be remembered that the cost coefficients and incidence data
24 436 may be derived from inadequate data, so sensitivity analysis is may be advisable. ~~There is the prospect~~
25 437 ~~of updating the CoI estimates as new or better data become available.~~ Due to non-standardisation of
26 438 technique (e.g. different components, and assumptions), comparability between studies is awkward.

439 440 3.2.68. Health adjusted life years (Burden of Disease)

441 Scope: 'Health adjusted life years (HALY)' are nonmonetary health indices, where the actual health of
442 an individual is compared with a perfect health situation (usually on a scale from 0 to 1) and this score
443 is then multiplied by the duration of that health state. A descriptive summary of the various HALYs is
444 presented by Mangen et al. (2014).

445 Application area: HALY measures may be applied when the ranking of hazards is to consider the level
446 of human disease or loss of productive capacity for the exposed population, i.e., the burden of disease.
447 HALY estimates such as disability adjusted life years (DALYs) or quality-adjusted life years

(QALYs) may be used as the only parameter for risk ranking, but are often included as one of several parameters in a risk ranking model. The DALY method was developed at the WHO, and the Global Burden of Disease (GBD) study is the most often referenced source of disability weights for specific disease outcomes (www.who.int/healthinfo/global_burden_disease/metrics_daly/en/). The HALY approach has been applied to rank different pathogens and chemical contaminants in the same food category, different hazard-food category combinations, or summarised and ranked for different food categories. Estimates of DALYs or QALYs have also been used to rank waterborne contaminants in lakes or water supplies as well as for ranking human risk factors in general.

Approach: Data are required for estimating the number of cases with the most relevant types of acute illnesses, chronic sequelae and mortality (also termed health outcomes) arising from exposure to the hazards under consideration. Different types of hazards (chemical, microbiological or nutritional) require different types of data and modelling approaches (Crettaz et al., 2002; Hofstetter, 2002; Mangen et al., 2010; Mangen et al., 2014; Pennington et al., 2002), but after the final DALY/QALY calculations have been made, the risks estimates should be readily comparable. DALY/QALY estimates may also be included in several of the other risk ranking methods such as RA (Howard et al., 2007); Newsome et al. (2009); ~~Chen et al. (2013)~~, CRA (Lim et al., 2012), MCDA (Ruzante et al., 2010), risk matrixes, flow charts/decision trees or in expert syntheses.

Strengths and weaknesses: HALY methodologies readily allow comparisons between very different types of hazards, not only food related hazards but all types of human risk behaviour over time and geographical regions as presented by the Global Burden of Disease Study 2010 (Lim et al., 2012) and ECDCs initiative for developing methodologies for measuring current and future burden of communicable diseases (Mangen et al., 2014).

DALYs and QALYs are semi-quantitative estimates based on disability scoring, and their accuracy is highly dependent on the quality of input data and risk assessment models used for estimating the incidences of relevant health outcomes. In the applied studies, the methods for estimating the incidences of relevant health outcomes varied widely. The estimated DALY or QALY values seem to be relatively precise quantitative estimates, and there is a risk of over-interpretation of the relative differences, if the level of uncertainty is not addressed. A general methodological weakness is

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8 476 inadequate evidence to estimate the incidences of chronic disability, especially in cases with few or no
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10 477 symptoms during the acute phase of a disease. Another methodological weakness is that the concept of
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12 478 DALYs assumes a continuum from good health to disease, disability, and death which is independent
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14 479 of time – a concept not universally accepted. Also, stakeholders have difficulty to understand the
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16 480 concept and what is meant by it.
17 481 Perspectives for use by risk managerstakeholders: Tools are readily available for calculating DALYs
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19 482 for a range of infectious diseases including foodborne zoonoses in the EU (BCoDE tool from ECDC).
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21 483 If RA or models for estimation of reported cases are available, the resources needed to estimate
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23 484 DALYs are moderate. However, development of RA models to estimate the number of diseased
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25 485 individuals can in some instances be very time-consuming.
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27 486 DALY or QALY estimates can be viewed as an economic measure of human productive capacity,
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29 487 enabling ranking of the ‘societal production losses’ related to the included hazards. If HALY estimates
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31 488 from different studies are to be used in risk ranking, then differences in the methodology employed
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33 489 and the comparability of the studies must be considered. For monitoring purposes, risk ranking models
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35 490 estimating HALYs can be constructed so that yearly input of surveillance and population data can be
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37 491 entered, as done for the food borne pathogens in the Netherlands (Bouwknegt et al., 2013).

3.2.7. Stated preference methods

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39 493
40 494 ~~Scope: Stated preference methods could be used to elicit the preferences of individuals (citizens and~~
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42 495 ~~households) for reducing the risk from a range of food-related diseases. When aggregated they show~~
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44 496 ~~society’s preferences for risk reduction. These methods take into account the concerns and perceptions~~
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46 497 ~~of society and, consequently, the ranking produced may be different from that produced by experts on~~
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48 498 ~~technical grounds alone.~~

49 499 ~~Application area: There is a relatively long history of the use of stated preference techniques for~~
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51 500 ~~valuing non market goods in the analysis of environmental problems. So far, their application in~~
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53 501 ~~ranking food safety risks is limited and largely confined to valuing individual disease reduction~~
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55 502 ~~measures or comparing alternative risk management options within single food disease problem, see~~
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57 503 ~~e.g., Mørkbak & Nordström (2009) and Miller et al. (2005). Golan et al (2005) concluded that, at~~
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8 504 ~~present, there is not a coherent set of guidelines for conducting such studies, making comparability~~
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10 505 ~~between studies difficult. In theory, these methods could be used to rank diseases, disease food~~
11 506 ~~combinations, or stages in supply chains. However, it is a complicated technique to use, which might~~
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13 507 ~~explain the lack of use for ranking more than a small number of alternatives.~~

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15 508 ~~Approach: Using stated preference methods, a simulated market is constructed and monetary values~~
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17 509 ~~are derived from hypothetical questions. The methods include stated preference techniques~~
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19 510 ~~(contingent valuation and discrete choice experiments) and averting behaviour or preventative~~
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21 511 ~~expenditure, which is the cost of preventing illness. In contrast to the CoI approach, stated preference~~
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23 512 ~~methods include the value individuals place on other factors for which no markets exist such as, for~~
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25 513 ~~instance, (not) experiencing pain. Stated preference methods are also able to include the value of lost~~
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27 514 ~~health in people who are not in the labour force (e.g. retired) who are excluded from CoI calculations.~~

28 515 ~~One of the stated preference methods, willingness to pay (WTP) rests on the observation that people~~
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30 516 ~~make trade-offs between health and other goods and services. The approach elicits the resources an~~
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32 517 ~~individual is willing to give up for a reduction in the probability of encountering a hazard that will~~
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34 518 ~~compromise their health (Golan et al., 2005). As an example, Mørkbak and Nordström (2009)~~
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36 519 ~~conducted a choice experiment to elicit WTP for campylobacter free chicken as compared to the~~
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38 520 ~~alternatives, non-labelled chicken and outdoor reared chicken; in other words, the WTP for higher~~
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40 521 ~~food safety compared to the current level. This approach defines the choices which individuals make~~
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42 522 ~~in terms of the levels of key attributes (such as high/low price, probability of illness etc) which are~~
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44 523 ~~associated with each of the goods being compared.~~

45 524 ~~Strengths and weaknesses: WTP is generally viewed as the most complete and correct economic~~
46
47 525 ~~welfare measure of the benefits of food safety policies. This is because, like CoI, WTP includes the~~
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49 526 ~~cost of treatment and lost productivity but also (unlike CoI) changes in consumer welfare such as pain,~~
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51 527 ~~distress and inconvenience (Hoffmann, 2010). Both individual and societal WTP can be calculated. A~~
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53 528 ~~useful feature is that stated preferences may be linked to participant profile revealing which societal~~
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55 529 ~~groups (e.g., by age, background) ranks a particular risk most highly (see Haninger and Hammitt~~
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57 530 ~~(2014) for an example). The aggregated value of benefits (or societal WTP) of food safety (e.g.,~~

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8 531 ~~reduced risks) can be compared with the costs for achieving them since both costs and benefits are~~
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10 532 ~~expressed in monetary units.~~

11 533 ~~However, WTP is a difficult technique to apply, and is prone to errors and bias unless conducted~~
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13 534 ~~meticulously. Experience so far has been in comparing only 2 to 4 alternative risks. It may be possible~~
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15 535 ~~to elicit mean WTP for a larger number of risks, but the scope of choice experiments may be limited~~
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17 536 ~~by the capacity of participants to choose between a large number of choice sets encompassing many~~
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19 537 ~~attributes. Moreover, WTP reflects the ability to pay, and implicitly assumes that the existing~~
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21 538 ~~distribution of resources in society is acceptable (Golan et al., 2005). However, because WTP studies~~
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23 539 ~~can produce results segmented by sub population, they may draw attention to unequal distributional~~
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25 540 ~~impacts which should be considered in policy making.~~

26 541 ~~Perspectives for use by stakeholders. These techniques provide a means to incorporate societal~~
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28 542 ~~preferences in ranking and decision making. However, experience in the food safety field as yet is~~
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30 543 ~~only modest, and there is scope to develop techniques still further.~~

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33 545 3.2.89. Multi-Criteria Decision Analysis (MCDA)

34 546 ~~Scope: MCDA is an approach which has the potential to evaluate multiple - often conflicting - criteria~~
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36 547 ~~in decision making. It allows for comparison of different risks on common basis, by simultaneous~~
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38 548 ~~consideration of provides a fairly transparent means of identifying the salient parameters of a problem~~
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40 549 ~~(technical information, uncertainty and different stakeholder preferences), and can potentially include~~
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42 550 both quantitative and qualitative data, ~~and and~~ the integration of large amounts of complex
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44 551 information, ~~to allow for comparison of different risks on a common basis. MCDA has a long history~~
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46 552 ~~of use in various decision contexts, e.g., in nanomaterial risk assessment. MCDA is typically applied~~
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48 553 ~~to decision making problems with multiple, often conflicting, criteria that need to be evaluated. It~~
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50 554 helps structuring and solving problems, ~~such to enable making leading to~~ more informed and better
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52 555 decisions. ~~In the context of risk ranking, important criteria utilized in food safety can be identified~~
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54 556 ~~through a process of expert or lay consultation, which may include not only public health impacts but~~
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56 557 ~~also perception, costs – an in case of interventions – also weight of evidence, and practicality~~
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58 558 ~~associated with the interventions~~

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8 559 Application area: MCDA can be applied to any range of problems, which can be defined in terms of a
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10 560 common set of criteria. As the scientifically 'best' solution may be inadequate in terms of acceptability
11 561 to society, utilize resources which or not available, or be sub-optimal in terms of allocating resources,
12 562 stakeholder methods are sometimes used to capture the preferences of consumers, citizens and/or
13 563 experts. ~~Hence, stakeholder engagement can feature in MCDA in particular when politically~~
14 564 ~~acceptable solutions are to be defined. Indeed,~~ MCDA which combines expert judgement across a
15 565 range of relevant criteria appears to be the second most popular method for relative risk ranking of
16 566 microbiological hazards, after RA.

17 567 Approach: MCDA is a semi-quantitative method in which a range of different criteria are identified
18 568 against which each problem is assessed. Participants, either experts, ~~(e.g., (FAO and WHO, 2012),~~
19 569 stakeholders or lay people ~~(Fazil et al., 2008),~~ can be supplied with technical information in relation to
20 570 each risk criterion to assist their deliberations. The selection of preference functions and weights are
21 571 an integral and core part of the MCDA methodology and must be selected when conducting a risk
22 572 ranking. An example is provided by Ruzante et al. (2010) who utilized the method to develop a
23 573 prioritization framework for foodborne risks that considered not only public health impacts but also
24 574 market impact, consumer risk acceptance and perception, and social sensitivity. For each risk under
25 575 consideration, participants give each criterion either a numerical score or an ordinal ranking such as
26 576 'high', 'medium' and 'low'. In an MCDA, a key issue that could differentiate the possible approaches
27 577 is whether weights are applied to criterion scores and, if so, how they are elicited. At the simplest
28 578 level, , criteria could be considered as equal, which, however, may result in the oversimplification of
29 579 experts' views. Alternatively, experts can allocate weights for each MCDA criterion, thereby
30 580 indicating the degree of importance they put on each criterion in the MCDA outputs. The weighted
31 581 scores are then combined to produce a single score for each issue, permitting scores to be ranked.
32 582 Another well-known example of a MCDA method for ranking pathogen-produce combinations is the
33 583 Pathogen-Produce Pair Attribution Risk Ranking Tool (P³ARRT) developed by FDA (Anderson et al.,
34 584 2011), which is available free (<http://foodrisk.org/exclusives/rrt>). Fazil et al. (2008) applied MCDA
35 585 for the ranking of food safety interventions, considering amongst others cost, effectiveness, and weight
36 586 of evidence. MCDA methods and applications vary in their complexity; they may even allow for

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8 587 | probabilistic modelling and sensitivity analyses. Recently, alternative methods for performing a
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10 588 | MCDA have been developed and employed, e.g., by Havelaar et al. (2010), in order to minimise the
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12 589 | biases linked with experts' direct weighting of the MCDA criteria.

13 590 | Strengths and weaknesses: MCDA allows consideration of stakeholder perceptions by using the
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15 591 | weights and preference functions they assign to the various criteria in the analysis. Furthermore,
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17 592 | economic impact or other criteria that are deemed relevant can be included, in addition to human
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19 593 | health criteria. This makes the method broadly applicable, allowing risk assessors/managers to
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21 594 | determine the impact of various criteria on the overall risk ranking of hazards. This method, therefore,
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23 595 | allows inclusion of subjective elements that may also be important for risk managers to include in their
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25 596 | decision making processes, depending on the aim of the ranking exercise. Alternative scenarios using
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27 597 | weights and preference functions for various input factors can be compared. However, MCDA
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29 598 | outcomes are more difficult to communicate compared ~~top~~ more straightforward methods such as risk
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31 599 | matrices or scoring methods, as various criteria are included, which are weighted and prioritized often
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33 600 | each having differently weights. Furthermore, this method needs expert or stakeholder input in order
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35 601 | to derive the weights and preference functions for the criteria. Therefore this method has weaknesses
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37 602 | that are linked to the elicitation of information from experts (see below), i.e., the need for having
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39 603 | rigorous, auditable methods to identify experts; high demand for resources (as training of experts in
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41 604 | these methods and specialised risk analysts and modellers may be needed); the need to consider how
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43 605 | to elicit experts' own uncertainties regarding their views, opinions, judgments; and - last but not least
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45 606 | – the need to consider possible ways to combine individual opinions without masking variability in the
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48 608 | Perspectives for use by risk managerstakeholders: This systematic method is very valuable in cases
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50 609 | where stakeholder perceptions are required to be included in the risk ranking, as ~~a~~-weights and
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52 610 | preference functions can be assigned to the various model variables. This method also allows the
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54 611 | inclusion of factors other than effect and exposure endpoints, e.g. from the social-economic field, or in
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56 612 | terms of policy development, which makes it a very versatile tool. The application of MCDA will
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58 613 | provide a single number for ranking. However, the underlying calculations can be difficult for the non-
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60 614 | expert to understand for those without expertise in the methodology grasp.

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10 616 3.2.10. Stated preference methods

11 617 Scope: Stated preference methods could be used to elicit the preferences of individuals (citizens and
12 618 households) for reducing the risk from a range of food-related diseases. When aggregated they show
13 619 society's preferences for risk reduction. These methods take into account the concerns and perceptions
14 620 of society and, consequently, the ranking produced may be different from that produced by experts on
15 621 technical grounds alone.

16 622 Application area: There is a relatively long history of the use of stated preference techniques for
17 623 valuing non-market goods in the analysis of environmental problems. So far, their application in
18 624 ranking food safety risks is limited and largely confined to valuing individual disease reduction
19 625 measures or comparing alternative risk management options within single food-disease problem, see
20 626 e.g., Mørkbak & Nordström (2009) and Miller et al. (2005). Golan et al (2005) concluded that, at
21 627 present, there is not a coherent set of guidelines for conducting such studies, making comparability
22 628 between studies difficult. In theory, these methods could be used to rank diseases, disease-food
23 629 combinations, or stages in supply chains. However, it is a complicated technique to use, which might
24 630 explain the lack of use for ranking more than a small number of alternatives.

25 631 Approach: Using stated preference methods, a simulated market is constructed and monetary values
26 632 are derived from hypothetical questions. The methods include stated preference techniques
27 633 (contingent valuation and discrete choice experiments) and averting behaviour or preventative
28 634 expenditure, which is the cost of preventing illness. In contrast to the CoI approach, stated preference
29 635 methods include the value individuals place on other factors for which no markets exist such as, for
30 636 instance, (not) experiencing pain. Stated preference methods are also able to include the value of lost
31 637 health in people who are not in the labour force (e.g. retired) who are excluded from CoI calculations.

32 638 One of the stated preference methods, willingness to pay (WTP) rests on the observation that people
33 639 make trade-offs between health and other goods and services. The approach elicits the resources an
34 640 individual is willing to give up for a reduction in the probability of encountering a hazard that will
35 641 compromise their health (Golan et al., 2005). As an example, Mørkbak and Nordström (2009)
36 642 conducted a choice experiment to elicit WTP for campylobacter-free chicken as compared to the

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8 643 alternatives, non-labelled chicken and outdoor-reared chicken; in other words, the WTP for higher
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10 644 food safety compared to the current level. This approach defines the choices which individuals make
11 645 in terms of the levels of key attributes (such as high/low price, probability of illness etc) which are
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13 646 associated with each of the goods being compared.

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15 647 Strengths and weaknesses: WTP is generally viewed as the most complete and correct economic
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17 648 welfare measure of the benefits of food safety policies. This is because, like CoI, WTP includes the
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19 649 cost of treatment and lost productivity but also (unlike CoI) changes in consumer welfare such as pain,
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21 650 distress and inconvenience (Hoffmann, 2010). Both individual and societal WTP can be calculated. A
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23 651 useful feature is that stated preferences may be linked to participant profile revealing which societal
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25 652 groups (e.g., by age, background) ranks a particular risk most highly (see Haninger and Hammitt
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27 653 (2011) for an example). The aggregated value of benefits (or societal WTP) of food safety (e.g.,
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29 654 reduced risks) can be compared with the costs for achieving them since both costs and benefits are
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31 655 expressed in monetary units.

32 656 However, WTP is a difficult technique to apply, and is prone to errors and bias unless conducted
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34 657 meticulously. Experience so far has been in comparing only 2 to 4 alternative risks. It may be possible
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36 658 to elicit mean WTP for a larger number of risks, but the scope of choice experiments may be limited
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38 659 by the capacity of participants to choose between a large number of choice sets encompassing many
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40 660 attributes. Moreover, WTP reflects the ability to pay, and implicitly assumes that the existing
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42 661 distribution of resources in society is acceptable (Golan et al., 2005). However, because WTP studies
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44 662 can produce results segmented by sub-population, they may draw attention to unequal distributional
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46 663 impacts which should be considered in policy making.

47 664 Perspectives for use by risk manager. These techniques provide a means to incorporate societal
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49 665 preferences in ranking and decision making. However, experience in the food safety field as yet is
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51 666 only modest, and there is scope to develop techniques still further.

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53 668 3.2.9. Risk matrices

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55 669 Scope: Just like the scoring methods, risk matrices also make use of scoring both exposure and effect
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57 670 endpoints. The difference between scoring methods and risk matrices is that, in the latter, the exposure

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8 671 ~~and effect endpoints are not aggregated by multiplication or addition, but are depicted in a risk ranking~~
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10 672 ~~matrix with effect on the one axis and exposure on the other.~~

11 673 ~~Application: This method is usually applied to chemical or microbiological hazards for which limited~~
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13 674 ~~quantitative data are available. This method has, for example, been applied for ranking the risks of~~
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15 675 ~~nanomaterials (O'Brien and Cummins, 2011; Sorensen et al., 2010; Zalk et al., 2009).~~

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17 676 ~~Approach: Both the likelihood of occurrence and the consequences of the hazard for human health are~~
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19 677 ~~scored into one of several classes; see Figure 2 for an example. Classes that could be used for~~
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21 678 ~~likelihood of occurrence are: almost certain, likely, possible, unlikely and rare. Classes that could be~~
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23 679 ~~used for the consequences are: insignificant, minor, moderate, major and severe. Then, risk classes are~~
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25 680 ~~assigned to the combinations of Likelihood and Consequences, e.g., being L (low), M (moderate), H~~
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27 681 ~~(high), and E (extreme), as shown in Figure 2. Risk classification may also be based on scores. Zalk et~~
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29 682 ~~al. (2009), for example, classified nanomaterials based on scores for probability and severity, and the~~
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31 683 ~~results were depicted in a risk matrix. The results can also be visualized using spider web plots, as~~
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33 684 ~~conducted by, (e.g.), Ranke and Jastorff (2000), who classified various endpoints using scores from 1-~~
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35 685 ~~4, and compared plots for the various compounds to obtain an indication of the most risky ones.~~

36 686 ~~Strengths and weaknesses: The risk matrix method is qualitative or semi-quantitative, and thus less~~
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38 687 ~~accurate than methods based on concentration data and dose response relationships or toxicological~~
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40 688 ~~reference values. It provides a visualisation for both effect and exposure of the hazard, giving direct~~
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42 689 ~~insights into the way these two elements contribute to the overall risk of a hazard. For example, a~~
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44 690 ~~hazard may present a high risk due to a high exposure, although its severity is low. Alternatively, due~~
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46 691 ~~to its high toxicity, it may present a high risk rank despite low exposure. Matrices will give more~~
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48 692 ~~information to the risk manager compared to other methods that produce a list of hazards according to~~
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50 693 ~~the overall risk alone. However, the classification for consequences and likelihood may not be fully~~
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52 694 ~~underpinned by the available data. Furthermore, the method depends on expert input, requiring a~~
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54 695 ~~rigorous expert elicitation study.~~

55 696 ~~Perspectives for use by stakeholders: In case stakeholders prefer a graphical representation of the~~
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57 697 ~~risks, this method can be used to visualize both the effect and the exposure of a hazard. This facilitates~~
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59 698 ~~discussions amongst stakeholders regarding the risks of various hazards.~~

3.2.10. Flow charts

Scope: Flow charts or decision trees are based on a set of clearly defined questions or criteria. By following these, the hazards can be classified into different categories (e.g. high, medium or low) with respect to their risk for human health.

Application: Flow charts or decision trees can be used for various purposes. In general these methods are used to obtain a qualitative indication about the risks associated with hazards. Haase et al. (2012), for example, established a decision tree for nanoparticles to determine whether a full risk assessment is required or not. EFSA described guidelines for classifying chemical hazards as negligible, low, medium, and high risks (EFSA, 2012c, 2012d).

Approach: A flow chart is generally based on several questions that need to be answered in order to arrive at a certain risk class. Questions can be based on the likelihood that specific chemicals or microbiological hazards are present in the study object; evidence of occurrence or incorrect practice in the food chain, the toxicological profile, and the outcome of national monitoring programmes (EFSA, 2012c, 2012d). Eisenberg and McKone (1998) used a Classification and Regression Tree Algorithm (CART) to specify the chemical and environmental properties and Monte Carlo simulations to estimate human exposure. Schmidt et al. (2011) utilized a decision support system (DSS) to rank genetically modified organisms (GMOs), based on a decision tree and rules, indicators and baselines, and thresholds (such as the LD50) (Schmidt et al., 2011). DSS may also be combined with multi-criteria decision analysis (MCDA). Critto (2007), for example, utilised a DSS system to evaluate ecological observations and ecotoxicological tests for contaminated sites and then incorporated MCDA and expert judgments into the ranking. This approach might also be used for ranking food safety risks.

Strengths and weaknesses: Flow charts/decision trees present a straightforward method with clear questions for which only qualitative information is needed, although quantitative information can be used where available. The method can, thus, be used for a quick screening of food safety hazards, in order that the most relevant ones may subsequently be investigated in more detail. However, this method strongly depends on expert input and it is, therefore, essential to perform a rigorous expert

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8 727 ~~elicitation study. Furthermore, this type of method is vulnerable to being less transparent than other~~
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10 728 ~~methods, as it is not always clear why hazards end up being classified as a high, medium or low risk.~~
11 729 ~~Therefore, for each hazard classified based on a decision tree or flow chart, the underlying reasons for~~
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13 730 ~~the answers should be clearly documented in order to obtain a transparent classification.~~
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15 731 ~~Perspectives for use by stakeholders: It is important to set up the right questions for inclusion in a flow~~
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17 732 ~~chart/decision tree based on expert judgment and scientific evidence, which may be challenging to~~
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19 733 ~~achieve. However, once a decision tree has been drafted, it is easily applicable for stakeholders to~~
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21 734 ~~classify hazards into high, medium and low risks.~~

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736 3.2.11. Expert judgement

737 Scope: Expert judgement-based methods elicit rankings from citizens, stakeholders or other experts,
738 and have the potential to produce a systematic and transparent ranking of risks.

739 Application area: Three principal applications of judgement-based risk ranking were identified: a)
740 achieving a ranking when there are data gaps, b) reconciling the diverse information streams and
741 considerations encountered in multi-attribute problems, and c) incorporating societal values (e.g.
742 (Moffet, 1996). The inclusion of public perceptions, priorities and values may result in a different
743 ranking being reached to that derived from using scientific experts alone. This might reflect public
744 concerns such as whether the distribution of costs and benefits is equitable, the characteristics of the
745 people likely to be affected (e.g. children or elderly people), whether exposure to the risk is voluntary
746 or involuntary, and whether there is 'dread' or fear of a catastrophic impact (DeKay et al., 2005).

747 Approaches: A variety of methods is available, for application in workshops or in surveys, which may
748 be characterised by the flows of information which take place between the participants and the
749 research team (Rowe and Frewer, 2005). There may be a one-way flow of information from experts
750 (or other stakeholders) to researchers, which aims to capture participants' existing knowledge and
751 experience. Alternatively, there may be a two-way flow, whereby participants are provided with
752 detailed scientific and socio-economic information on which to base their deliberations and ranking,
753 which is finally communicated to the researchers. Formal semi-quantitative techniques exist to
754 combine divergent data sources, e.g., MCDA and the Carnegie-Mellon approach. In MCDA these

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8 755 | ~~approaches~~, the judgement of stakeholders is used ~~to rank risks and~~ to allocate weights and potentially
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10 756 | also on the way to weight the different criteria and in establishing the preferences to the different
11 757 | attributes whereas the Carnegie-Mellon approach produces risk rankings. to produce a multi-attribute
12 758 | ranking. Approaches also vary according to whether they involve experts or lay people, the amount of
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14 759 | technical information about risks and impacts that is provided to assist study participants, whether the
15 760 | approach is qualitative or semi-quantitative, and whether or not the process involves deliberation
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17 761 | among participants. Four approaches were identified:
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21 762 | - Expert elicitation, defined as a set of formal research methods used to characterize uncertainty
22 763 | about scientific knowledge and to provide alternative parameter estimates when there are
23 764 | meaningful gaps in available data (Batz et al., 2012). Commonly used approaches are
24 765 | workshops and the Classical Delphi method (Van der Fels-Klerx et al., 2002).
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26 766 | - Survey based on existing knowledge of lay or expert participants (i.e. minimal technical
27 767 | communication during the study), as applied by, e.g., Schwarzinger et al. (2010) and Harrington
28 768 | (1994).
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30 769 | - Ranking achieved through deliberation only, or deliberation with supporting technical
31 770 | information (e.g. focus group or workshop). Although the ranking process may be restricted to a
32 771 | panel of experts considering scientific data only (e.g. FAO/WHO, 2008), there is also the
33 772 | possibility to involve lay people and thus capture societal values.
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35 773 | - Carnegie-Mellon approach which was specifically developed as a standardised procedure by
36 774 | which several risks could be ranked, and involves the elicitation of the explicit preferences of
37 775 | lay groups (DeKay et al., 2005). The basic procedure requires expert technical inputs to define
38 776 | and categorize the risks to be ranked, to select attributes by which the risks are characterised,
39 777 | and to prepare risk summary sheets to assist deliberations on each risk (Florig et al., 2001).
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41 778 | - ~~Ranking~~ of risks is performed by lay people (not experts) in a workshop setting according to
42 779 | their levels of concern about the risks, having considered the information provided on the risk
43 780 | summary sheets. If used, weights for each attribute are obtained from each participant and
44 781 | reflect social value judgements. The procedure used for weighting is much simpler than that
45 782 | typically used in MCDA (DeKay et al., 2005).
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8 783 Strengths and weaknesses: Judgement-based methods provide additional information to that of
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10 784 technical assessments, e.g., when a problem is poorly understood, or technical data are incomplete.
11 785 The outputs commonly include a narrative component which can make explicit the interpretations and
12 786 assumptions which underlie the final ranking, as well as identifying the difficulties and uncertainties
13 787 which determine its limitations. They also provide a means of engaging the general public in
14 788 evaluative and decision-making processes and of incorporating societal preferences for different
15 789 alternatives. However, judgement-based methods require a very careful design if they are to provide
16 790 valid outcomes. Biases are introduced by a number of means including: inappropriate selection of the
17 791 participants; the framing of the problem(s) for consideration; the way the process is conducted such
18 792 that the whole range of opinions may not be elicited and recorded, and the content of the technical
19 793 information that is presented to participants (e.g. bias, comprehensibility, acknowledgment of its
20 794 limitations). Due to this need for meticulous preparation the method is often resource intensive.
21 795 Furthermore, a qualitative analysis of data (if required) makes heavy time demands both in the
22 796 transcription of audio recordings and their subsequent (thematic) analysis.

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33 797 Perspectives for use by ~~risk manager-stakeholders~~: Unless judgement-based methods are planned and
34 798 executed well there is a danger that they will be biased and unreliable. Depending on the specific
35 799 method, the output may be a simple ranking, but could also be a lengthy narrative which, though
36 800 having explanatory power, requires lengthy consideration. These methods can provide input in cases
37 801 where crucial data are missing, and a decision needs to be made. Also, they could provide a means of
38 802 incorporating societal values into risk ranking.

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41 805 DISCUSSION AND CONCLUSIONS

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48 807 A ~~systematic literature~~ review has been performed on method~~ologies~~ for ranking risks related to
49 808 chemical, microbiological and nutritional hazards in food, on the basis of their anticipated effects on
50 809 human health. The results showed that a range of risk ranking method~~ologies~~ has been applied
51 810 depending on the purpose of the specific study. They ~~various methods~~ have been grouped into eleven

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8 811 main categories, determined primarily by the type(s) of hazard that can be ranked, data needs, and
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10 812 uncertainty. Some methods allow ranking of different hazards types (chemical, microbiological),
11 813 whereas others allow ranking only within one hazard category.
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13 814 Four of the eleven method groups can be applied to all three types of hazards (microbiological,
14 815 chemical and nutritional), either alone or in combination, these being MCDA, risk matrices, stated
15 816 preferences techniques, and expert synthesis. For microbiological hazards, there is a close relationship
16 817 between exposure and resulting levels of illness and death, which allows CoI and DALY/HALY
17 818 calculations to be made. With chemical contamination of food, there is no such direct relationship
18 819 between the contamination and resulting diseases/deaths in the population, since effects on human
19 820 health are long-term and, hence, the cause-effect relationship is difficult to establish. Consequently,
20 821 these methods ~~is~~ are not often applied to chemical food contamination, although an exception is the
21 822 study by Kemmeren et al. (2006) who calculated DALYs for chemical contaminants, using
22 823 assumptions on the relations between chemical food contamination and disease outcomes. Although
23 824 health effects of nutritional hazards are often evident only in the longer term, recent improved
24 825 availability of insights from long-term epidemiological studies on the cause-relationships between
25 826 nutritional hazard and disease outcomes sometimes allow ~~-COI~~ and DALY/HALY be applied to
26 827 nutritional hazards. Risk assessment methodology can be applied to chemical hazards and
27 828 microbiological hazards, when it is known as quantitative microbiological risk assessment (QMRA).
28 829 Although the same procedure is followed, the calculations and the information required are quite
29 830 different. Both RA types aim to calculate human exposure to a particular food safety hazard - the
30 831 chemical contaminant and the pathogen, respectively – through food consumption. The main
31 832 difference is that MRA calculates the pathogenic contamination of food at time of consumption and
32 833 numbers of people getting ill from consuming that food, whereas chemical RA calculate the exposure
33 834 of the contaminant by food at the time of consumption and evaluate if this exposure is below or above
34 835 the Tolerable Daily Intake (ADI), or similar. For ranking several chemical contaminants in food at
35 836 once, methods typically applied are the risk ratio method and the scoring method. These methods
36 837 either multiply or divide a parameter for occurrence of the chemical (e.g. concentration) and the
37 838 severity of the hazard (e.g. TDI).

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8 839 MCDA was mostly applied to rank microbiological hazards, but could also be applied for ranking
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10 840 chemical hazards, or both. However, when applied to ranking two or even three types of hazards (if
11 841 nutritional hazards are included), great care must be taken in designing the MCDA so that a common
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13 842 set of parameters are identified which are relevant to all hazard groups.
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15 843 For some methods, such as risk matrix and risk ratio, essential data needs appear to be smaller than
16 844 with other methods, like RA, CRA and MCDA. However, it is more that these former methods could
17 845 also be applied when less information is available, although ideally larger amounts would be available.
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19 846 This is in contrast to the latter methods that have a large demand of quantitative data and can only be
20 847 applied when these data are available. When new, additional data become available, this should be
21 848 processed by the method selected in order to update risk ranking results. Automatic or easy updating
22 849 of results is an issue that was hardly touched upon in the risk ranking method application found in
23 850 literature, but this issue merits further investigation. In addition, automatic or easy updating of results
24 851 could also be used for the scenario analyses or sensitivity analyses of results. It requires an IT
25 852 application of data, stored in datasheets or databases, linked to model calculations expressed in scripts.
26 853 Methods most suitable for such an automatic update are RA, risk ratio, risk scoring, risk matrices,
27 854 COI, HALY, and MCDA. It is more difficult to apply with CRA, WTP and expert synthesis. For WTP
28 855 and expert synthesis, the context in which participants make their choices will be altered (e.g. changes
29 856 in relative prices or perceived risk), and hence primary data will need to be collected again with the
30 857 method designed to reflect the altered context.
31 858 Methods that apply quantitative approaches demand more data and result in more precise outcomes
32 859 with a better description of the uncertainties, assuming that data quality is high. Qualitative methods
33 860 can be used when data are scarce, e.g., when emerging hazards, such as botanicals, are to be ranked.
34 861 They also have the advantage of generating rich descriptive material, by which insights into the
35 862 reasoning behind the opinions (or ranking decisions) of participants can be obtained. In the cases of
36 863 limited data availability, the appropriate methods are risk matrix, flow charts/decision trees with an
37 864 emphasis on input from experts, or a ranking based solely on expert synthesis of available quantitative
38 865 and qualitative information. In the cases of the latter, use qualitative inputs, the outcomes will also be
39 866 less precise.

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8 867 In general, quantitative methods taking into account uncertainty and variability require more time and
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10 868 resource than qualitative methods. However, most methods that are used for qualitative situations can
11 869 also be used semi-quantitatively ~~by~~ or quantitatively. And in the latter case, they would also require an
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13 870 equal amount of time and resource. For instance, risk matrices and expert judgements can be used in a
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15 871 simple application using qualitative input or asking the expert to provide their qualitative opinion,
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17 872 respectively. When performed more quantitatively also expert judgement and risk matrices are also
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19 873 resource intensive.

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21 874 In principle, all methods can account for uncertainty and variability in the input data used,
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23 875 ~~Acknowledging this information is more precise and quantitatively defined with the quantitative~~
24 876 methods. RA and CRA, both of which can accommodate uncertainty and variability in the input data,
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26 877 appear to be very useful methods for providing quantitative results, provided their substantial data
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28 878 requirements are met. ~~In general, methods that apply quantitative approaches demand more resources~~
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30 879 ~~and result into more precise outcomes with a better description of the uncertainties. Semi-quantitative~~
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32 880 ~~and qualitative methods could also allow for inclusion of uncertainty. Two methods do not have the~~
33 881 ~~capacity to consider uncertainty in terms of outcomes, these being risk matrix and flow/decision~~
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35 882 ~~charts. Some methods allow ranking of different hazards types (chemical, microbiological), whereas~~
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37 883 ~~others allow ranking only within one hazard category.~~

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39 884 ~~RA and CRA, both of which can accommodate uncertainty and variability in the input data, appear to be~~
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41 885 ~~very useful methods for providing quantitative results, provided their substantial data requirements are~~
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43 886 ~~met. More qualitative methods could be used when data are scarce, e.g., when emerging hazards, such~~
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45 887 ~~as botanicals, are to be ranked. In the cases of limited data availability, the appropriate methods are~~
46 888 ~~MCDA, risk matrix, flow charts/decision trees with an emphasis on input from experts, or a ranking~~
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48 889 ~~based solely on expert judgement.~~

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50 890 Risk ranking can be based on a narrow range of parameters, e.g., measurements of exposure and effect
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52 891 on human health, such as risk ratio or the scoring method, or can include wider issues such as
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54 892 economic impacts and societal preferences. Most methods are demanding of time and other resources,
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56 893 e.g., for primary data collection, although some predefined tools for risk ranking are openly available
57 894 exist. MCDA is typically applied when, besides exposure and effect, other metrics need to be

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8 895 considered, such as the consumers' perception of risk associated with different hazards. The strength
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10 896 of this method is in this wider applicability and the involvement of stakeholder groups to assess
11 897 preference functions and weights. It is often applied in a multi-stakeholder situation. WTP is typically
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13 898 applied when consumer perception on food safety is to be included in the risk ranking.

15 899 The results of risk rankings should be interpreted carefully as relatively small differences in
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17 900 methodology can result in changes in final rankings. There is a need for transparency regarding the
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19 901 method used and its application and adequate explanation so users can understand the rationale which
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21 902 has been used to derive the numbers.

22 903 An important element of all risk ranking activities is communication of the outputs to interested end-
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24 904 users, including the general public. A question arises as to how such communication processes are
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26 905 developed from the outputs of these different risk ranking methodologies in forms which are both
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28 906 understandable and relevant to different interested end-user communities, and there is no comparative
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30 907 analysis currently available. Including risk perceptions may, for example, increase the relevance of the
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32 908 outputs to the general public, but the extent to which such communication is trusted compared to the
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34 909 communication of outputs from risk ranking methodologies where this has not been the case requires
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36 910 further research, as does the development of a more general communication strategy regarding risk
37 911 ranking practices and allocation of resources to associated risk mitigation activities.

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41 913 In conclusion, this study showed there is a wide range of methods that can be used for ranking food
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43 914 related hazards, based on their impact on human health. It has demonstrated that there is no single best
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45 915 risk ranking method. Each of the method categories has its own strengths and weaknesses. The most
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47 916 suitable methods should be selected based on the risk manager's requirements and needs, (as well as
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49 917 available resources), the risk ranking task at hand, data availability and the characteristics of the
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51 918 methods. To this end, close communication between risk managers and risk assessors is needed to
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53 919 identify- to the most suitable method for risk ranking. Uncertainties associated with data input need to
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55 920 be clearly stated. To date, this is not part of the standard procedure of most methods.

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57 921 This overview is valuable for industrial and governmental risk managers, and risk assessors for
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59 922 selecting the most appropriate methods for risk ranking of food and diet related hazards on the basis of

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8 923 human health impact. The overview will facilitate this decision process and allow for a structured and
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10 924 transparent selection of the most appropriate risk ranking method.

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1222 LEGENDS TO FIGURES

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1224 **Figure 1:** Framework for risk ranking of chemicals, adapted from Bu et al. (2013).

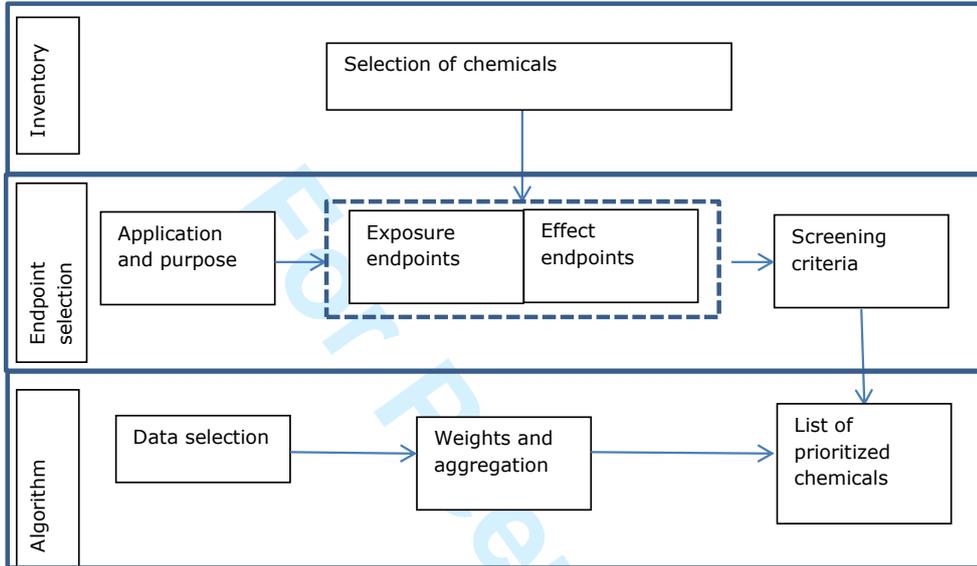
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1226 **Figure 2:** Example of Risk matrix

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1228 Figure 1.



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1231 Figure 2

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Severe
Almost certain	M	H	H	E	E
Likely	M	M	H	H	E
Possible	L	M	M	H	E
Unlikely	L	M	M	M	H
Rare	L	L	M	M	H

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1233 Table 1: Results of the literature search in the two-tier approach

Type hazard/field	Tier 1: Title, abstract, keywords			Tier 2: Full text	
	Not relevant	Maybe relevant	Relevant	Not relevant	Relevant
Chemical hazards	5769	79	173	5943	101
Microbiological hazards	2601	74	257	2844	110
Nutritional hazards	979	58	12	1045	4
Health adjusted live years	90	13	9	98	18
Socio-economic methods	3296	47	15	3366	20

1234

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1236 Table 2: Number of references per method categories for risk ranking of the food and/or nutritional
 1237 hazards

Type hazard	Risk assessment	Comparative risk assessment	Ratio	Scoring	Cost of illness	Health Adjusted LY	Stated preference ¹	MCDA ¹	Risk Matrix	Flow chart	Expert synthesis
Chemical	19	0	31 ²	19 ³	1 ²	9 ^{3,4}	1 ²	13	12	13	0
Microbiological	72	0	6 ²	5 ³	9 ²	19 ³	6 ²	4	4	7	14
Nutritional	4	3	1	0	0	1 ⁴	0	1	0	2	0
Other	0	0	0	0	0	0	1	1	0	0	1
Sum	95	3	38	24	10	29	8	19	16	22	15

¹WTP: Willingness to Pay; HALY; health adjusted live years, MCDA: Multi Criteria Decision

Analyses;

²One reference described both chemical and microbiological hazards;

³Three references described both chemical and microbiological hazards;

⁴One reference described both chemical and nutritional hazards.

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8 1244 **ANNEX 1. Literature search protocol**

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12 1246 a) Search strategy and search strings

13 1247 The search strategy consisted of three major steps, each designed to search titles and subject headings.

14
15 1248 Combinations of search strings were used, starting with a broad screening for methods for risk ranking

16
17 1249 and prioritisation in the field of food related issues (step 1), then narrowing down the methods relating

18
19 1250 to size of anticipated impact on human health (step 2), and finally focusing on chemical hazards,

20
21 1251 biological hazards, nutritional components, or social issues related to food (step 3). The strategy steps

22 1252 and final search strings are as follows:

23
24 1253 **Step 1:** Captured titles/subject headings that studied methods and tools for risk ranking and

25
26 1254 prioritization related to food issues. This step included the following search strings:

27
28 1255 TOPIC = (risk*¹ OR hazard*) AND

29
30 1256 TITLE = (categor* OR rank* OR method* OR nomogram* OR matric* OR decision* OR

31 1257 priori* OR analys* OR mc*a OR multi-criteri* OR assessment*) AND

32
33 1258 TOPIC = (food* OR agri* or agro*OR environ*) AND

34
35 1259
36
37 1260 **Step 2:** Captured titles/subject headings that investigated risk ranking and prioritisation methods on

38
39 1261 the basis of anticipated health impact. This step included the following search terms:

40
41 1262 TOPIC = (disease* OR human health* OR *tox* OR illness* OR cost* OR sever* OR adi*

42 1263 OR tidl* OR epidemiol* OR BoD OR wtp OR incidence OR prevalence)

43
44 1264 TOPIC = ("socio* impact" OR "econ* impact" OR WTP OR cost* OR WTA)

45
46 1265
47
48 1266 **Step 3:** Captured titles/subject headings that investigated specific application fields of biological

49
50 1267 hazards, chemical hazards, nutritional components in food, or social science issues related to food

51
52 1268 hazards, from consumer and governance perspectives. This step included the following search strings:

53 1269 TITLE = (zoonos* OR microb* OR gen* OR pathogen* OR qmra OR "antimicrobial

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55 1270 resistance" OR parasite* OR virus* OR bacteria* OR micro*rgan* OR prion* OR TSE* OR

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57 1271 QRA) AND

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8 1272 NOT = benefit*

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10 1273 OR:

11 1274 TITLE = (nano* OR chemic* OR antibiotic* OR dioxin* OR "heavy metal*" OR carc* OR
12 1275 pesticid* OR "plant protection product*" OR hormon* OR mycotoxin* OR phytotoxin* or
13 1276 phycotoxin* or marine biotoxin* OR Biocid* OR *contam* OR *pollutant* OR Melamin*
14 1277 OR Acrylamid* OR PCB* OR Residu* OR Endocr* OR Mutag* OR Botanic* GMO* OR
15 1278 "Genetic* modif*" OR "Novel protein*" OR Allerg* OR Insecticid* OR Acaricid* OR
16 1279 Herbicid* OR Fungicid* OR "plant growth regulat*" OR POP OR POPs OR Persistent* OR
17 1280 *accumul*) AND
18 1281 NOT = benefit*

19 1282 OR

20 1283 TITLE = (*nutri* OR *diet* OR bioavail* OR *supplement* OR "Novel protein*" OR
21 1284 Fortification* OR "Novel food*" OR Allerg*) AND
22 1285 NOT (toxic* OR microbial* OR chemic* OR socio* OR benefit*)

23 1286

24 1287 DALY/QALY concept:

25 1288 TOPIC = (daly* OR qaly* OR haly* OR HRQL* OR HALE) AND
26 1289 NOT = benefit*

27 1290

28 1291 OR

29 1292 TOPIC = ("focus group*" OR survey* OR interview* OR public* OR "expert analys*" OR
30 1293 *attitud* OR *percep* OR Willingness* OR *Soci* OR Determ* OR Cultur* OR Tradition*
31 1294 OR Typic* OR Consumer* OR Ethic* OR accept* or opinion* or view* or behaviour* or
32 1295 behavior* or employ* or communicat* or dialog* or engage* or particip* or gover* or legal*
33 1296 or law* or regul*) AND
34 1297 NOT: religious* or halal* OR benefit*

35 1298

36 1299 b) Evaluation criteria

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8 1300 The references judged to be relevant for the study objectives were evaluated for eligibility and quality

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10 1301 of the described research. References were included when:

11 1302 1. Reference was relevant for the objective of the literature review;

- 12
13 1303 o References discussing prioritisation/ranking methods for human health risks and/or,
14
15 1304 o References describing risk prioritization/ranking methods applied for
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17 1305 environmental/ecological risks and/or,
18
19 1306 o References to risk prioritization, risk analysis, risk assessment methods and/or risk
20
21 1307 modelling included in abstract and/or,
22
23 1308 o Any relevance of the work for application to human health, including references on
24
25 1309 drinking water and/or,
26
27 1310 o Abstract indicates socio-economic research methodology is employed.

28 1311 2. Reference came from international peer-reviewed journals;

29
30 1312 3. Methods in the reference were well described, (semi-)quantitative or qualitative, user-friendly,
31
32 1313 transparent, structured, and objective;

33 1314 4. Methods in the reference were applicable in wider decision making schemes/frameworks;

34
35 1315 5. In case of reports, they should originate from well-known, highly-respected governmental
36
37 1316 bodies or research organisations.

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41 1318 Criteria for excluding references were:

42 1319 - References discussing only parts of a method (only exposure or only human health effects),
43
44 1320 such as references dealing with presence of chemical hazards, analytical methods, and/or

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46 1321 references about toxicity studies. These are all parts of a risk assessment and/or,
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48 1322 - References addressing non-human related aquaculture and non-human related animal health.
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1323 Table 3. Characteristics of risk ranking methods related to food safety

Characteristic	Risk Assessment	Comparative Risk Assessment	Ratio (Exposure/Effect)	Scoring method	Cost of Illness	HALY ¹	WTP ¹	MCDA ¹	Risk Matrix	Flow charts /Decision trees	Expert Synthesis
Amount of resources (time, money)	High	High	Moderate	Moderate	Moderate	Moderate	High	Moderate/High	Low	Low	Moderate /Low
Level of output	Quantitative	Quantitative	Semi-quantitative	Semi-quantitative	(Semi-) quantitative	(Semi-) quantitative	(Semi-) quantitative	Semi-quantitative	Qualitative/semi-quantitative	Qualitative	Qualitative
Easy to explain to stakeholders (laymen)?	No	No	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes
Inclusion stakeholder perception	Not possible	Not possible	Not possible	Possible	Not possible	Not possible	Possible	Possible	Not possible	Possible	Possible
Inclusion uncertainty	Possible	Possible	Possible	Possible	Possible	Possible	Possible	Possible	Not possible	Not possible	Possible
Inclusion weights for the risk ranking criteria	Not possible	Not possible	Not possible	Possible	Not possible	Not possible	Not possible	Possible	Not possible	Not possible	Possible
Inclusion human incidences	Possible	Possible	Not possible	Not possible	Possible	Possible	Possible	Possible	Not possible	Possible	Possible
Inclusion economic impact	Not possible	Not possible	Not possible	Not possible	Possible	Not possible	Possible	Possible	Not possible	Possible	Possible
Common method of communication (in addition to reports)	Graphs/Tables	Graphs/Tables	Tables	Tables	Graphs/Tables	Graphs/Tables	Graphs/Tables	Graphs/Tables	Graphs	Decision Tree	Tables
Essential data needed DATA Needs											
Human incidence data needed?	No	Yes	No	No	Yes	Yes	Yes	No	No	No	No
Dose-response data needed?	Yes	Yes	No	No	No	No	No	No	No	No	No
Occurrence data (concentration, prevalence, dose) needed?	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
Food consumption data needed?	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
Growth models needed (only applicable for microbiological hazards)?	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No

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1324	Toxicological reference values (ADI, TDI etc) needed (only applicable for chemical hazards)?	Yes	Yes	Yes	No						
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¹WTP: Willingness to Pay; HALY; health adjusted live years, MCDA: Multi Criteria Decision Analysis

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