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Advancing food, nutrition, and health research in Europe by connecting and building research infrastructures in a DISH-RI: Results of the *EuroDISH* project

Harriëtte M. Snoek, Lars M.T. Eijssen, Marjolein Geurts, Cecile Vors, Kerry A. Brown, Marc-Jeroen Bogaardt, Rosalie A.M. Dhonukshe-Rutten, Chris T. Evelo, Leopold Fezeu, Paul M. Finglas, Martine Laville, Marga Ocké, Giuditta Perozzi, Krijn Poppe, Nadia Slimani, Inge Tetens, Lada Timotijevic, Karin Zimmermann, Pieter van 't Veer



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Summary

Background

Research infrastructures (RIs) are essential to advance research on the relationship between food, nutrition, and health. RIs will facilitate innovation and allow insights at the systems level which are required to design (public health) strategies that will address societal challenges more effectively.

Approach

In the EuroDISH project we mapped existing RIs in the food and health area in Europe, identified outstanding needs, and synthesised this into a conceptual design of a pan-European DISH-RI. The DISH model was used to describe and structure the research area: **Determinants** of food choice, **Intake** of foods and nutrients, **Status** and functional markers of nutritional health, and **Health** and disease risk.

Key findings

The need to develop RIs in the food and health domain clearly emerged from the EuroDISH project. It showed the necessity for a unique interdisciplinary and multi-stakeholder RI that overarches the research domains. A DISH-RI should bring **services** to the research community that facilitate network and community building and provide access to standardised, interoperable, and innovative **data** and **tools**. It should fulfil the scientific needs to connect within and between research domains and make use of current initiatives. Added value can also be created by providing services to policy makers and industry, unlocking data and enabling valorisation of research insights in practice through public-private partnerships. The governance of these services (e.g. ownership) and the centralised and distributed activities of the RI itself (e.g. flexibility, innovation) needs to be organised and aligned with the different interests of public and private partners.

1 Advancing food, nutrition, and health research in Europe by connecting and 2 building research infrastructures in a DISH-RI: results of the *EuroDISH* 3 project

4 Harriette M Snoek^{1,2,a}, Lars MT Eijssen^{3,4}, Marjolein Geurts⁵, Cecile Vors⁶, Kerry A Brown⁷, Marc-Jeroen
5 Bogaardt¹, Rosalie AM Dhonukshe-Rutten², Chris T Evelo^{3,4}, Leopold Fezeu⁸, Paul M Finglas^{9,10}, Martine
6 Laville⁶, Marga Ocké⁵, Giuditta Perozzi¹¹, Krijn Poppe¹, Nadia Slimani¹², Inge Tetens¹³, Lada Timotijevic⁷,
7 Karin Zimmermann¹, Pieter van 't Veer²

8 Affiliations: ¹Wageningen Economic Research; ²Division of Human Nutrition, Wageningen University, The
9 Netherlands; ³European Nutrigenomics Organisation, NuGO Association, Wageningen, The Netherlands;
10 ⁴Department of Bioinformatics – BiGCaT, NUTRIM School of Nutrition and Translational Research in
11 Metabolism, Maastricht University, The Netherlands; ⁵National Institute of Public Health and the
12 Environment, Bilthoven, The Netherlands; ⁶Centre Européen pour la Nutrition et la Santé (CENS),
13 Université Claude Bernard Lyon 1, France; ⁷Food Consumer Behaviour and Health Research Centre,
14 University of Surrey, UK; ⁸Université Paris 13, Equipe de Recherche en Epidémiologie Nutritionnelle
15 (EREN), Centre de Recherche en Epidémiologie et Statistiques, Inserm (U1153), Inra (U1125), Cnam,
16 COMUE Sorbonne Paris Cité, F-93017 Bobigny, France; ⁹EuroFIR AISBL, Brussels, Belgium; ¹⁰IFR-
17 Institute for food research, Norwich, UK; ¹¹CREA-NUT, Food & Nutrition Research, Rome, Italy;
18 ¹²International Agency for Research on Cancer, Lyon, France; ¹³Risk-Benefit Research Group, National
19 Food Institute, Technical University of Denmark;

20 ^a Corresponding author

21 **Summary**

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24 nutrition, and health. RIs will facilitate innovation and allow insights at the systems level which are
25 required to design (public health) strategies that will address societal challenges more effectively.

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27 In the EuroDISH project we mapped existing RIs in the food and health area in Europe, identified
28 outstanding needs, and synthesised this into a conceptual design of a pan-European DISH-RI. The DISH
29 model was used to describe and structure the research area: **Determinants** of food choice, **Intake** of
30 foods and nutrients, **Status** and functional markers of nutritional health, and **Health** and disease risk.

31 **Key findings**

32 The need to develop RIs in the food and health domain clearly emerged from the EuroDISH project. It
33 showed the necessity for a unique interdisciplinary and multi-stakeholder RI that overarches the research
34 domains. A DISH-RI should bring **services** to the research community that facilitate network and
35 community building and provide access to standardised, interoperable, and innovative **data** and **tools**. It
36 should fulfil the scientific needs to connect within and between research domains and make use of

37 current initiatives. Added value can also be created by providing services to policy makers and industry,
38 unlocking data and enabling valorisation of research insights in practice through public-private
39 partnerships. The governance of these services (e.g. ownership) and the centralised and distributed
40 activities of the RI itself (e.g. flexibility, innovation) needs to be organised and aligned with the different
41 interests of public and private partners.

42 **Key words**

43 Research infrastructures; public health; roadmap; governance; policy; nutrition

44 **Introduction**

45 The increasing prevalence of obesity and diet-related chronic diseases is one of the major societal
46 challenges in the European Union (EU). Therefore, the development of effective public health nutrition
47 strategies is an urgent effort (European Commission, 2011). Research in the food, nutrition, and health
48 area could support the development of such strategies, especially when alignment with policy agendas
49 and between the different research domains is ensured. Building research infrastructures (RIs) is a way
50 to support research communities in terms of research quality, alignment, and cost-efficiency (Snoek,
51 Dhonukshe-Rutten et al., submitted). In particular the food and health research area which is highly
52 complex and multidisciplinary can benefit from RIs (ERA, 2013; Brown et al., 2017). The European
53 Strategy Forum on Research Infrastructures (ESFRI) defined RIs as unique facilities (such as buildings
54 and equipment), resources (such as platforms, databases, and biobanks), or services (such as data
55 management procedures and networks) (ESFRI, 2011). Along this definition, RIs include both "hard"
56 resources (tangible, material or physical infrastructure such as buildings, equipment, and knowledge-
57 containing resources) and "soft" resources (procedures, training, and networks).

58 For the food and health area, RIs can enable the scientific community to (Snoek et al., submitted):

- 59 1) Conduct top level research;
- 60 2) Provide access to methodologies and data, allowing innovation and harmonisation in data collection,
61 data sharing and mining;
- 62 3) Exploit the European diversity of food cultures,
- 63 4) Align to societal challenges in the EU as well as to priorities in each of the EU countries, and
- 64 5) Support capacity building and bridge the knowledge gap between EU regions.

65 RIs can also be beneficial for stakeholders outside the research community such as policy makers, civil
66 society and industry by facilitating access to data and knowledge and network building. For example, it
67 can assist policymakers at national and EU levels by increasing the availability of and access to reliable
68 evidence on effective (public health nutrition) strategies. It can facilitate researchers to link with non-
69 governmental organisations which are themselves important contributors to research as representatives
70 of affected populations. Such links can for example facilitate patient and public participation in research
71 which may lead to improved design and execution of research (Vayena, 2014; Vayena et al 2015). Also,
72 RIs can provide a suitable model for partnerships between food industry and public institutions,
73 exchanging data and know-how while taking into account the differences in interests and mandates.

74 In order to get insights in RIs in the food, nutrition, and health area, the EuroDISH project
75 (<http://eurodish.eu>) mapped the existing RIs in Europe, identified gaps, and defined needs (Snoek et al.,

76 submitted). Then, in this project the results were synthesised into a conceptual design of what is needed
77 to fully support future research in the field, and outlined in a roadmap on how to achieve this. A main
78 conclusion was that there are needs for developing and strengthening RIs in each of the research fields
79 on **Determinants** of food choice, **Intake** of foods and nutrients, its relation to **Status** and functional
80 markers of nutritional health, and **Health** and disease risk (DISH model). Additionally, the project
81 identified a unique need for a research infrastructure (a DISH-RI) that overarches these fragmented
82 research domains and the domain-specific RIs. This paper elaborates on the results of the EuroDISH
83 project and describes the characteristics and added value of a proposed *pan-European DISH-RI*. We also
84 discuss how generation of a knowledge leap in the food, nutrition and health area will empower
85 innovative research and public health nutrition (PHN) strategies to contribute more effectively in
86 addressing societal challenges.

87 **Approach**

88 The EuroDISH project was a three year EU 7th framework project that started in September 2012 (for
89 more details see Snoek, Dhonukshe-Rutten et al., submitted). During the project a mapping of existing
90 RIs in the DISH domains was done using a combination of desk research and 30 semi-structured
91 interviews (Brown et al, submitted) and key governance aspects were identified based on a combination
92 of desk research and semi-structured interviews with key stakeholders of eight existing RIs. Parallel to
93 this, two RI case studies were conducted: 1) Nutrition surveillance RI for integration of existing food
94 consumption and composition platforms, and 2) RI for integrative mechanistic molecular nutrition
95 research. In the final stage of the project a conceptual design as well as a roadmap for implementation
96 of a DISH-RI were developed as reported in this paper. This was based on project outcomes, the case
97 studies, workshops with external stakeholders, and EuroDISH consortium meetings

98 **DISH-RI in the European research landscape**

99 Figure 1 depicts the wider European research (infrastructure) landscape around DISH domains with the
100 adjacent domains of agri food and health and examples of existing RI's. DISH-RI could be positioned as
101 an overarching RI, unique for the area, interdisciplinary and can unify the emerging, yet separate
102 dedicated RIs at different stages of development. To achieve this, it should offer services relevant to all
103 domains within the field and making sure that these are well aligned with the wider research landscape.

104 **Established and emerging RIs within the DISH domains**

105 EuroDISH mapping showed that a substantial number of food and health specific RIs were already
106 emerging in the Status and Health domains, and to a lesser extent in the Intake domain. For the
107 Determinants domain this was, however, less evident (Brown et al, submitted). To further demonstrate
108 possibilities, advancements, and gaps of current RIs, two case studies were conducted for the Intake,
109 Status and Health domains. Case study one followed the development of a dietary surveillance RI,
110 specific to the Intake domain, yet also relevant to all DISH domains. The aim was to advance the
111 software that is used to connect food composition databases. The non-profit association EuroFIR
112 (eurofir.org) offers a food composition data platform and software (based on formerly EPIC-Soft) for
113 collecting standardised food consumption data. This work is continued as the global nutrition surveillance
114 initiative (GloboDiet) by the international agency for research on cancer – World Health Organisation
115 (IARC-WHO). GloboDiet aims to develop and validate a standardized method for dietary assessments and

116 provide the tools, support, and training for implementation. Case study two followed the development of
117 a nutritional phenotype RI, connecting the status and health domains. This case study built upon work
118 conducted previously by NuGO-network partners. NuGo (nugo.org) is an association of universities and
119 research institutes that among other goals aims to shape a nutrition bioinformatics structure and as part
120 of that offers a Nutritional Phenotype database (dbNP.org) to capture study data and metadata. This
121 collective work has now been incorporated into the Joint Action ENPADASI (European Nutritional
122 Phenotype Assessment and Data Sharing Initiative), funded by the Joint program initiative healthy diet
123 for a healthy life of the EC (JPI-HDHL, healthydietforhealthylife.eu). In addition to the tools mentioned in
124 the case studies, EuroDISH partners have driven the development of a Determinants and Intake relevant
125 RI via contributions to the H2020-funded RI-design project RICHFIELDS (richfields.eu) that aims to
126 develop an infrastructure of linked open data on consumer behaviour relevant to food, nutrition, and
127 health.

128 A further clear-cut EuroDISH finding was that RIs to link research across DISH domains were lacking.
129 DISH-RI would unify and extend the emerging RIs in the food, nutrition, and health research area and
130 align these initiatives along the DISH domains. By doing so, it would have the potential to fulfil the needs
131 of the research community represented within the whole DISH spectrum.

132 **Initiatives and RIs outside the DISH domains**

133 *Outside* the DISH domains, numerous RIs are already present in the EU research landscape. It is
134 essential to utilise the experience of existing RIs on specific adjoining topics. For example, biobanking
135 and biomolecular resources RI (BBMRI-eric.eu) has knowledge on knowledge of handling of biological
136 materials. The Consortium of European Social Science data Archives (CESSDA.eu) has experience with
137 integrating national archive data and providing access for secondary data analysis. Other relevant
138 initiatives are the managing of biological data and data platforms in ELIXIR, a RI in the area of life
139 sciences (elixir-europe.org) and the integration of standards in BioMedBridges, a cluster of biomedical
140 sciences RIs (biomedbridges.eu) and the related Corbel project (corbel-project.eu). Also for more general
141 aspects of RIs such as governance, data standardisation and sharing, reducing fragmentation of
142 research, capacity building lessons can be learned from other RIs. Finally, formal agreements with
143 existing RIs are important to avoid duplication of work and to ensure alignment of technical support,
144 facility-sharing, business models, governance principles, etc.

145 The food, diet, and health research area is positioned between two adjacent research areas: the agrifood
146 and health care sectors. Both areas are of importance for underpinning the development of policies and
147 strategies on food production, processing and reformulation. Data, information and knowledge from
148 these sectors can enrich data on food composition, food safety, environmental sustainability and
149 economic aspects. This would be informative to for example discussions on recommended fish
150 consumption and biodiversity, or circular economy and food safety, transport and safety (e.g. EHEC).
151 Analogously, in the health care sector, developments in e-health and personalised treatment may be
152 relevant to data protection and personalised nutrition strategies, respectively.

153 **Research agenda setting and funding**

154 Eventually, the DISH-RI is envisioned to serve the research needs and advance the food, nutrition, and
155 health research community, while the research itself is funded by national, European or global
156 mechanisms and public or private bodies. Since RIs act as a research facilitator and not as a data owner,

157 the DISH-RI can become an instrumental research platform for food, nutrition, and health topics. Such a
158 platform can provide unique possibilities for improved interactions between the food production area,
159 food industry and nutritional and health research. Similarly, DISH-RI can provide data and services to
160 support development of policy strategies by international or national funding organisations and
161 authoritative bodies. Examples of these are UN organisations (such as WHO, FAO, World Food Council)
162 EC organisations (such as EFSA), disease specific organisations (such as the World Cancer Research
163 Fund), and semi-private organisations (such as the Gates Foundation). Within this context, DISH-RI can
164 benefit from synergies with the JPI-HDHL. JPI-HDHL has already established an organisational structure
165 involving many countries and raising supporting research funding for food, nutrition, and health related
166 topics.

167 **How DISH-RI can meet user needs: data, tools, and services**

168 An overarching DISH-RI was considered necessary to facilitate access to (yet) unavailable i) **'data'** that
169 could span across different studies, countries, disciplines and DISH domains; ii) **'tools'** to generate and
170 exploit data such as standardised, harmonised, innovative instruments and methodologies; iii) **'services'**
171 to facilitate the scientific research community and other societal stakeholders to access the data and
172 tools. This is visualised Figure 2 showing the conceptual design of DISH-RI.

173 **Data**

174 **Connecting data over the DISH: opportunities for public health policies**

175 The diagram in Figure 3 illustrates how several types data on food and health may play a role in the
176 process of defining health policy targets. Epidemiological studies, RCTs, mechanistic, translational, and
177 clinical studies assess the associations between food, nutrition and health and disentangle the underlying
178 (patho)physiological mechanisms, i.e. the upward sloping line in Figure 3). Nutritional surveillance and
179 health examination surveys assess the nutritional adequacy and nutritional health of defined populations,
180 based on the current intake distribution for food and nutrients and/or biomarkers of nutrition-related
181 disease risk; in figure 3 the observed intake distribution is represented by the bell-curve at the right side
182 of the X-axis. It represents the intake of either nutrients, foods or both of them combined in a healthy
183 diet indicator. These association-data and food dietary intake distribution together serve as a basis for
184 setting policy targets, here represented by the horizontal dotted line that represents the risk or 'policy
185 target that is defined to be acceptable to policymakers or health authorities. The vertical dotted line at
186 the intersection with this policy target identifies the desirable level of dietary exposure and can help e.g.
187 EFSA and national health councils to set their targets on dietary change. This is typically done by
188 authoritative expert committees that integrate the strength of scientific evidence in the light of societal
189 ambitions regarding public health. Finally, to reduce disease risk and arrive at the desired level of public
190 health, the intake distribution must be shifted to the left (in this example) to improve population health
191 and well-being and reduce health risks. This is where public health strategies, the food environment and
192 consumer choice comes in. Public health nutrition strategies build on research on the effectiveness of
193 intervention programmes and demographic and psycho-social determinants. To modify the exposure
194 distribution to desirable levels by e.g. actions in the economic domain, behavioural programmes, or food
195 reformulation. So all DISH-pillars are represented in this figure; moreover to go through this process in
196 a productive way, the interrelationship between the data from these pillars must be secured and
197 harmonized.

198 Connecting data within the DISH domains: current research developments and perspectives

199 To effectively support analyses, modelling, scenarios, and forecasting, the standardisation and
200 harmonisation of data, instruments, tools, and procedures is essential. Connections are needed within
201 and between research domains and countries. For example, in the intake domain, a representative pan-
202 European surveillance system on food and nutrient intake could provide insight in the diversity of EU-
203 food habits and nutritional adequacy across the life course (IARC-WHO joint global nutritional
204 surveillance, GloboDiet consortium). In the status domain, the two projects MIRDIEET and FOOTBALL in
205 the Joint Action of the JPI HDHL Biomarkers in Nutrition and Health will take the opportunity of
206 connecting several EU and national dietary intervention study results to highlight new valid biomarkers of
207 dietary intake and nutritional status.

208 Connecting data over the DISH domains: current research developments and perspectives

209 A DISH-RI could also foster connections over the research domains (Table 1). For example, linking intake
210 and determinant data could reveal determinants of behaviour that can be used in development of
211 interventions and policies. Other examples are linkages in the intake, status and health domains that can
212 add to the identification of reliable biomarkers and setting nutritional reference values, as a basis for
213 nutrient recommendations. Connections over the status and health domains can also add to the
214 understanding of biomolecular mechanisms, bioavailability, biomarkers of health, etc. This can in turn
215 lead to better prediction of health, more precise dietary advice, and personalised nutrition. In the end,
216 connecting over the whole DISH can add to an evidence-based and internally consistent picture on
217 effective public health nutrition strategies. Repositories on effective behavioural and intervention
218 strategies need to use the same concepts. Or, more realistically, mappings and tools to map concepts
219 commonly used in different domains need to be available. These concepts will allow for a connection
220 from drivers and barriers for dietary intake via nutritional and metabolic status markers to health
221 outcomes and policy measures.

222 Data enrichment, public and private stakeholders

223 Public and private stakeholders in the near environment of the DISH domains may enrich the presently
224 available data by unlocking currently unavailable existing, non-research data sources on food
225 consumption (e.g., retail) and on food composition (e.g., food industry), medical records, and large
226 administratively generated data such as social and employment records. An example of this is the
227 European Medical Information Framework (emif.eu) in which existing health data is efficiently reused for
228 research. Another example, in the western society, consumers leave traces of their food related activities
229 when they purchase (e.g. retail data, GPS), store in their fridge or produce waste (e.g. internet of things,
230 IoT) and consume (e.g. sensors, wearables). These data could potentially be used to assess lifestyle and
231 eating habits. Added value from public-private partnerships could also be created by enabling
232 valorisation of research insights in practice. This is relevant to for example food reformulations and
233 nudging consumers. Finally, public-private partnerships provide challenges for data quality and
234 comparability but also security and privacy issues – this will be discussed in the governance paragraph.

235 Future perspectives

236 The challenges of data linkage and sharing over the width of the food, nutrition, and health area are
237 enormous. For currently existing data, post-hoc standardisation and calibration are challenging. In the
238 future, the extension to big data, and more diverse and in part imprecise data poses even more
239 challenges. But, big data also offers many opportunities for research in all domains. For instance, data
240 that is collected through apps on smartphones and so-called wearable technology (smartwatches,

241 intelligent clothing) offers new perspectives. DISH-RI could enable researchers to take advantage of
242 these developments by bringing together ongoing initiatives in the DISH domains. A related development
243 is the shift from expensive data collection targeted to a specific research project, to or in combination
244 with more cost-efficient use of existing data. Data quality remains an issue, even with individual data
245 analysis, and could for example be secured in a shared tool for data quality appraisal. Finally, currently
246 dominant methods of systematic literature review and traditional plain meta-analyses of aggregated data
247 are expected to shift towards systematic querying of studies based on metadata followed by additional
248 integrative analyses of their resulting data or selected subsets thereof.

249 **Tools**

250 Although research data are increasingly obtained from existing non-research sources, most is still
251 generated within the context of scientific studies. Each disciplinary field has developed tools that fit its
252 own purposes. Integration of tools includes standards for current tools, post-hoc standardisation, and the
253 calibration of future tools to the current standards. DISH-RI could provide opportunities to view best
254 practices, most up to date methodologies, and opportunities for innovative design of new assessment
255 methods. Research opportunities also arise by connecting the instruments in use between the domains.
256 In this section we describe how development of methodologies and tools can contribute to answering key
257 research questions at a high level: "why do people eat what they eat?" (determinants-intake), "what do
258 people eat" (intake-status), and "how does it affect health?" (status-health).

259 **Why do people eat what they eat?**

260 Classical methodologies to assess determinants of food choice behaviour are survey data on (food
261 related) attributes, motives and values, and observations of food choices in (quasi) experimental
262 settings. More innovative measures include the emerging opportunities in IT and other technologies.
263 Examples of these are eye-tracking, facial expression coding, neuroscience, sensors e.g. on swallowing
264 food and imaging of the upper GI tract (De Graaf, 2012; Derks et al., 2015). Also, monitoring of
265 consumers in a constructed environment such as experimental supermarkets and using virtual reality
266 provides research data. Genetic and molecular determinants of, e.g., satiation, taste perception, are also
267 considered important determinants of food intake (Feeney et al., 2011). To effectively study the interplay
268 between all these aspects, there is a need for well-connected dedicated centres to address both biological
269 and behavioural determinants of food intake. Behavioural measures (e.g. physical performance in daily
270 life) of individuals, including patients, are increasingly embedded in diagnosis, support of daily
271 performance, e-medicine, etc. At the same time, adoption of food habits in childhood and learning new
272 habits has strong biological drivers. They are imprinted by physiological needs (hunger, satiation) and
273 cognitive neurological principles that are adopted in the context of families, schools or patient
274 communities. Thus, aligning the tools over the DISH range will help to arrive at truly interdisciplinary
275 research that connects the environmental, behavioural and biological determinants of food, nutrition, and
276 health.

277 **What do people eat?**

278 Classic dietary assessment methods of what people eat capture daily patterns in food intake e.g., Dietary
279 Histories, 24h recalls and food records. They have evolved into widely employed Food Frequency
280 Questionnaires in epidemiology and (replicated) 24h recalls in nutrition surveillance. Opportunities here
281 are standardisation of dietary assessment and food composition and the link between them. New
282 technologies are now becoming available via world wide web or mobile application based technologies
283 (e.g. ASA24, a self-administered 24 hour recall; see <https://epi.grants.cancer.gov/asa24/>) or via ICT-

284 based recording technologies of traditional assessment methods (e.g. app based prompts). Opportunities
285 here are to improve measurement error, low response, and response bias. Tools for the assessment of
286 eating habits may increasingly also be based on biomarkers. These are derived from the field of X-omics,
287 such as metabolomics and nutrigenomics, and developed towards targeted indicators of specific foods.
288 This was done for example in the projects JPI-FOODBALL, JPI-MIRDIET, and BIOCLAIMS that explored,
289 identified and validated biomarkers related to nutrition. Such functional markers can serve to evaluate
290 population health and nutritional needs. This was done for example by the EURRECA project to set
291 micronutrient dietary reference values (Van 't Veer et al., 2013).

292 **How does it affect health?**

293 The relation between nutrition and health is traditionally based on habitual intake and the resulting
294 nutritional status or risk factors (e.g. blood lipid profile, blood pressure). The biological variation in
295 nutritional status for people with the same food intake suggests that individual characteristics beyond
296 body composition and energy balance play a crucial role. For example, inter-individual differences in
297 micro-biotic composition are among the important factors determining the nutritional effect of food
298 intake. Tools to connect measures of diet and surveillance databases with nutrition biomarker and
299 nutritional status assessment are needed to highlight the impact of diet on nutritional health. To
300 investigate adverse effects (toxicology, safety) and risk-benefit assessment, connecting nutritional and
301 toxicological concepts and methodologies is required. The nutrition hub of ECRIN (an RI for clinical
302 research) allows to promote and to facilitate multinational clinical trials at European level to test the
303 effects of nutritional interventions on health parameters (Demotes-Mainard and Ohmann, 2005). Another
304 development in the field of status measures is the development of body composition and nutritional
305 needs assessment beyond the BMI, such as fat distribution, intra tissue fat, etc. Analytical tools and
306 equipment are being developed, such as DEXA and MRI for body composition. But also tools at the level
307 of metabolomics are being developed, such as indirect calorimetry for energy expenditure and substrate
308 oxidation, mass spectrometry and omics for plasma and tissue markers, etc. Developments in tools in
309 biostatistics and bioinformatics will allow going beyond single biochemical markers and use more
310 integrated non-invasive profiles of health and disease status. Moreover, the DISH area could benefit from
311 connecting to the life science RI ELIXIR to attach expertise related to generic data handling in genomics,
312 metabolomics and proteomics profiling.

313 **Beyond the data and tools: systems approach**

314 Integration of methodologies and data alone will not lead to understanding of how diet affects health and
315 how behaviour affects diet and thereby health and vice versa. What is also needed is interpretation of
316 results in terms of behavioural and biological models that represent our current knowledge. This requires
317 for instance collections of known metabolic processes and health-metabolism describing pathways. Also
318 systems biology models and resources that collect knowledge about interaction between
319 nutrients/metabolites and proteins, the genome, disease and so on need to be collected. These
320 collections can often be integrated with existing model collections (for instance at Biomodels,
321 WikiPathways and Reactome) but will benefit from maintenance, evaluation and curation by DISH-RI.

322 **Services**

323 Services are the things that the research community can get and/or "buy" from the RI such as access to
324 datasets, data processing procedures or attending training courses. A DISH-RI should provide technical
325 services to make data and tools accessible for researchers and stakeholders. Technological and
326 communicational services that support community building and networking are required for active

327 interaction between all stakeholders in the field. In addition, dissemination and implementation of
328 common standards, procedures and protocols can be facilitated through capacity building and training.
329 Finally, to ensure smooth operation, both the DISH-RI itself and the services it offers have to be
330 organised in terms of governance.
331

332 **Technical services**

333 Technical services that DISH-RI could provide are technological and scientific standards and strategies
334 for data collection, storage, and use. To support data collection, DISH-RI could for example provide
335 standardised items and scales or standardised protocols for testing tools. But it could also provide
336 models such as evaluation models, simulation tools, data integration models, network biology tools, etc.
337 An example of this are standards and software for quality control of collected food consumption and
338 composition data. This would build on the work of the food composition RI EuroFIR and software
339 developed by EuroFIR (partners): U-Menu, EPIC-Soft, e-SMP. For data storage and use DISH-RI could
340 provide several services as well. To support integrative analyses, data must be cleaned, calibrated, and
341 normalized. In addition, data sources must be clearly and consistently described. Data and tools must be
342 aligned upfront with unique ontologies for searching data. An example of this is a common language for
343 defining foods, nutrients and biomarkers. This also requires an e-infrastructure supporting the
344 interoperability, standardisation and quality management of data and tools. A DISH-RI could facilitate
345 access and needs to make data findable, accessible, interoperable and reusable (FAIR) for example
346 through a data portal (Mons et al., 2011). To make services available for users, a central entry point is
347 required with different interfaces (portals) for the different users, or connecting to different proceeding
348 points for the different types of services.

349 **Capacity building, training**

350 Access to data and tools is indispensable but so is knowledge on how to use the data, implement
351 standards and protocols, and perform data analyses (e.g. bioinformatics). Therefore, training and
352 capacity building (e.g. courses, summer schools, tutorials) are also needed. Examples of such services
353 include an overview of available data and standards and best practices on methodologies. Additionally,
354 data use can be facilitated by providing user friendly data analyses and visualisation services. Targeted
355 services could be provided for stakeholders outside academia, for instance in translating research
356 outcomes for policy makers and methodological support on research design for public and private non-
357 academic researchers. For example, insights on effectiveness of policies at European level are relevant
358 for policy makers and NGOs. However, for this purpose the data probably needs another level of
359 processing to become usable.

360 **Community building and networking**

361 Network services facilitate researchers within and between the different domains in working together and
362 exchange knowledge (e.g. conferences). This requires network-related and community building elements
363 that allow for integration of research communities within and between the different research areas. This
364 could be done by establishing centres of excellence and connecting these into an expert network. Such
365 (virtual) expert centres can develop transnational and multidisciplinary collaboration in research projects,
366 agenda setting, and funding. They can also provide tools and training for using these tools. Moreover,
367 the research community can benefit from the research outcomes that have emerged from earlier
368 successful (pan-EU) projects, joint-initiatives, and joint agenda setting. An example is the JPI-HDHL
369 funded Joint Action ENPADASI that facilitates data sharing for nutrition biomarker research. Another

370 example is the WHO-IARC Globodiet Initiative that aims to advance pan-EU nutrition surveillance by
371 using standardised approaches and interfacing and upgrading the GloboDiet and EuroFIR research
372 infrastructures. A final example is the Micronutrient Genomics Project portal with biological pathways for
373 many micronutrients.

374 **Governance**

375 Governance includes the governance of services, such as rules and conditions for access to data and
376 tools. Also ownership of data (public, private, consumers themselves) and privacy are of importance. In
377 addition, governance includes data management procedures such as confidentiality, data protection,
378 consent, level of harmonisation of data, security. Finally, governance is about the aspects related to the
379 organisational structure of the RI itself, such as membership, trust, voting rights, etc. EuroDISH made an
380 inventory of governance issues to be addressed, but did not make a final design for an organisational
381 structure of a DISH-RI. The project outcomes emphasised that DISH-RI should closely align with current
382 European research infrastructure models. For example, long-existing RIs such as ELIXIR (life sciences)
383 and ISBE (systems biology) can be used as examples as well as the model used by relevant European
384 research initiatives (e.g. JPIs like JPI-HDHL). In accordance with those projects, DISH-RI is projected to
385 be based upon the hub-spokes-nodes model with a central coordination hub and connected expertise
386 from different countries. The governance structure of such an RI organises centralised and distributed
387 activities, and enables flexibility regarding innovation within the RI. Innovation relates to innovations in
388 organisation and structure of the RI itself (e.g. election of a new chair) but also the possibility to adapt to
389 (unforeseen) innovations in the developments in the field. It is important for the governance model to
390 facilitate collaborations between different disciplines and for public-private partnerships. At the same
391 time it should take into account the different traditions in the research fields and different stakeholders
392 related to ownership, publication, etc. Collaboration with industry is a special point of interests since for
393 industry different interests and mandates will have to be reflected and discussed in the organisation of
394 an RI. For example, different rules and conditions for access of data owned by public institutes may exist
395 and similarly different rules may exist for the use of data owned by industry.

396 **Discussion of future perspectives**

397 **Starting point, summary of main EuroDISH outcomes**

398 A DISH-RI should bring **services** to the research community that facilitate network and community
399 building and provide access to standardised, interoperable, and innovative **data** and **tools**. Connection of
400 **data** over the DISH would enable analyses and modelling at a systems level. Other issues related to data
401 are connections to other areas (e.g. food safety or sustainability), data enrichment by public and private
402 stakeholders (e.g. food industry), and future developments such as big data, wearable tech, and joint
403 initiatives. Connecting data requires standards for **tools** (measurement instruments, study design and
404 computational methods), post-hoc standardisation, calibration of future tools to the existing ones, and
405 setting technological standards. An ICT backbone supporting the interoperability and quality
406 management of data and tools is an indispensable **service** for the research community to actually
407 benefit from the RI. Other technical and network services include customised portals for different users
408 and network services such as centres of excellence, capacity building and training, and joint agenda
409 setting. Governance services are needed to organise the access to data and tools in terms of

410 membership, ownership, privacy, and trust. Additionally, the governance of the RI itself should organise
411 the centralised and distributed activities and enable flexibility regarding innovation.

412 **Reflection on strengths and limitations of the EuroDISH project**

413 The final outcome of the EuroDISH project was a conceptual design as described in this paper; the actual
414 design phase of the proposed DISH-RI was beyond its scope. Also, the EuroDISH project has several
415 strengths and limitations that have to be considered. The main strength is that researchers from each of
416 the DISH domains were involved in the project, in all phases of the project public and private
417 stakeholders were involved, and the experiences of other RIs in the field were used. The main limitation
418 was that the mapping phase was done for each of the DISH domains but not across the domains, it was
419 not exhaustive and the choice of experts was mostly a convenience choice based on the network of the
420 consortium and through snowball sampling. A second limitation of the outcomes is that the main focus of
421 the project was on research needs and less attention was paid to capacity building. Especially considering
422 education and closing the knowledge gap between EU countries specific needs and implications for the
423 structure will have to be defined. Finally, the recommendations have been developed mostly with the
424 adult population in mind. More work is needed to have a better view on available data and gaps for
425 elderly and for younger populations. To develop this further, a life cycle nutrition approach could be used
426 as well as taking into account the ongoing changes in population structure. For example in the mapping
427 within the health domain a need to connect fertility and early nutrition programming research was
428 identified.

429 The DISH framework that was developed for the purpose of the project proved a useful way to describe
430 and structure the field of food and health research. At the same time it was recognized that there are no
431 strict borders between these conceptually different domains. Also, it became apparent that research on
432 dietary behaviour, intake assessment, biological mechanisms and clinical and epidemiological health
433 effects each tend to have their own traditions, standards, and scientific language. Furthermore, in each
434 disciplinary domain, governance issues like intellectual property and ownership have differentiated in a
435 way that serves their specific main purposes. These differences should be considered when designing the
436 RI.

437 **Roadmap and timeframe**

438 The long term ambition for a DISH-RI is to reach a fully operational status within a maximum of an 8 to
439 10-year time period. DISH-RI would then facilitate research via a distributed network of multidisciplinary
440 researchers in a virtual e-infrastructure.

441 **Next steps**

442 Building an RI requires a long endeavour. It encompasses needs assessment (already conducted in
443 EuroDISH), a design study, a preparatory and an implementation phase. When being developed, DISH-
444 RI will rely on European science and innovation funding mechanisms (e.g., H2020-INFRADEV and e-
445 infrastructures) aligned with political and financial support at the member state level. Building on the
446 EuroDISH experience, four countries (NL, DK, UK, IT) have initiated development of a European DISH-RI
447 Hub and national nodes in 2015-16. In this respect, alignment with the ESFRI roadmap for the Health
448 and Food area is of utmost importance. To ensure a close match between research priorities and the
449 enabling facilities of a DISH-RI at the national level, the member state funded RI will interact closely with
450 the agenda setting and research funding via the JPI-HDHL and H2020. The structure will be based on the
451 hubs and spokes model which requires setting up disciplinary focussed, technological expert centres in

452 different country-nodes. The initial core organisational infrastructure will have an inbuilt flexibility to
453 expand and to accommodate different types of data.

454 This implies that building DISH-RI will take several years and especially defining the business model and
455 governance structure will be a process of developing, building and negotiating. In terms of time and
456 efficiency, good use should be made of RI activities that are already going on within the DISH area and
457 from their experiences with organisation and governance. As part of this process, alliances will be built
458 with emerging RIs within the DISH domains. Yet at the same time, there is an urgency to proceed with
459 and not slow down current RI activities.

460 **Business model**

461 The prerequisite for a business model is that the RI fulfils essential needs of the research community and
462 that it is organised in a way that is focussed on delivering the services. As stated in the ESFRI definition:
463 the RI attracts researchers. In addition, a DISH-RI could attract stakeholders outside the research area
464 and bring services to policy makers, industry, and health professionals. From the experiences of ELIXIR
465 we have learned that this only works if the stakeholders see the benefit of such an infrastructure. But
466 also broad consensus should be achieved on practical and ethical issues related to data sharing. By its
467 very nature, the DISH-RI will stimulate data-stewardship and harmonisation which serves the
468 sustainability of data and results beyond the research projects as such. A unique asset of a DISH-RI is
469 that it not only enables research via public funding mechanisms at the member state or European level,
470 but also in the private domain, e.g. with food companies and medical partners.

471 **DISH-RI as facilitator of pan-European interdisciplinary research**

472 The DISH-RI will serve as a facilitator of interdisciplinary linkage. From the opportunities that it offers,
473 new combinations of research domains, methodologies, and scientific breakthroughs will emerge. For
474 example, future studies could become highly efficient by using linked and/or integrated assessment
475 tools. Moreover, public and private governed data sources or structured and unstructured 'big data' on
476 food composition, sustainability indicators, dietary habits and health status could mutually enrich each
477 other. Rather than separate cohorts, surveillance and community interventions, an integrated pan
478 European mixed longitudinal research framework could be envisioned that serves the linkage and
479 exchange of data between such studies and bridge the gaps between yet unrelated disciplines. Such
480 framework could start from an initial phase that describes the diversity of diets across Europe, e.g. with
481 sub-studies on nutritional effects and risk factors for disease. Next, depending on scientific and/or
482 public health challenges, sub-cohorts could be followed to address changes in dietary habits over time, to
483 link diet to health outcomes (aetiological and ecological studies). Additionally, personalised and
484 community interventions on either behavioural change, its determinants, and/or physiological health
485 outcomes can be conducted. Clearly, this requires not only a high degree of alignment and
486 standardisation of tools (standardised description/capturing using ontologies), but also requires a well-
487 accepted mechanism to determine the research agenda with the Member States and the European
488 Commission.

489 **Conclusion**

490 The EuroDISH-project clearly showed that food and health research could be advanced by a distributed
491 and/or virtual RI to connect existing RI and research activities. An overarching DISH-RI was considered
492 necessary to facilitate access to (yet un)available i) 'data' that could span across different studies,

493 countries, disciplines and DISH research areas; ii) 'tools' to generate and exploit data such as
 494 standardised, harmonised, innovative instruments and methodologies; iii) 'services' to facilitate the
 495 scientific research community and other societal stakeholders to access the data and tools. This will also
 496 allow for addressing today's societal challenges on public health nutrition strategies (e.g., behaviour
 497 change, food reformulation), food and nutrition security (e.g., agricultural food supply, nutrition
 498 requirements and dietary guidelines) and innovative food and health research (e.g., big data,
 499 personalised nutrition, applying a systems approach). Added value could also be created in public-private
 500 partnerships by unlocking data and enabling valorisation of research insights in practice. A DISH-RI
 501 should bring services to the research community that facilitate network and community building and
 502 provide access to standardised, interoperable, and innovative data and tools.

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 510 stakeholders involved in phase 1, 2, and 3 workshops for their contributions.

511 Figure captions

512 **Figure 1.** DISH-RI situated in the European research landscape. As an overarching RI unique for the
 513 food, nutrition, and health area it can connect emerging RIs in the food and health area and ensure
 514 sustainability of data, tools and services from research projects. It will closely align with RIs from
 515 adjacent agricultural, social, and biomedical disciplines as well as with public and private stakeholders in
 516 the agri-food sector (left) and the health care sector (right). See Brown et al., 2017 and Appendix A for a
 517 more detailed description of the RIs.

518 **Figure 2.** Conceptual design of EuroDISH outcomes on needs for RIs in the Food and Health research
 519 area. Columns represent and describe the DISH domains: **Determinants** of food choice, **Intake** of foods
 520 and nutrients, **Status** and functional markers of nutritional health, and **Health** and disease risk. Rows
 521 represent the data, tools and services that a DISH-RI should provide to achieve the scientific and societal
 522 impact described at the right side of the rows.

523 **Figure 3.** Conceptual model representing food and dietary patterns (horizontal axis), and the risk of
 524 adverse health or nutritional status outcomes on the vertical axis (left). See text.

525 Table

526 Table 1. Examples of data connections over the food and health research domains and their potential
 527 outcomes.

DISH domains	Data connection	Potential outcomes	Building on earlier initiatives
--------------	-----------------	--------------------	---------------------------------

Determinants – Intake	Multicentre studies on food cultures and policies including both determinants and behaviours	-Relate determinants to behaviours -Develop interventions and policies based on these relations	The JPI-HDHL Joint Action DEDIPAC (www.dedipac.eu , Lakerveld et al., 2014) started methodology mapping and research community building in the field of determinants of diet and physical activity.
Intake – Status	Connect measures of diet from surveillance with biomarkers of nutritional status	-Evaluation of nutritional adequacy -Reliable biomarkers of intake -Set nutritional reference values	-The FP6 Network of Excellence EURRECA (Van 't Veer et al. 2013) has identified and developed methodologies to standardise the process of setting micronutrient dietary reference values. -Development of pan-European Nutrition Surveillance principles is also supported by EFSA, e.g., http://onlinelibrary.wiley.com/doi/10.2903/j.efsa.2009.1435/epdf
Intake – Status	Absorption, distribution, metabolism, and excretion of nutrients and bioactives	- Link intake to bioavailability - Explore potential health effects - Biomarker selection - Dietary advice - Create computable models of biological pathways	For example controlled nutrition intervention studies and multicentre community intervention studies.
Intake – Status – Health	Heterogeneity in health and wellbeing across Europe as related to dietary intake and metabolic risk markers	Insight in the relationships between nutritional status and health and the underlying physiological and bio-molecular mechanisms	Using smart sampling schemes and modern assessment technologies, .e.g., as done by NuGO Association (nugo.org) Using ecological modelling of diet and health in Europe, e.g., as done in the SUSDIET project for sustainable diets in Europe (https://www6.inra.fr/sustainablediets)
Status – Health	Linking phenotype and genotype data	-Personalised nutrition approaches directed at subgroups who share nutritional traits or risk factors for diseases -Development of powerful biobanking and bioinformatics systems enabling data sharing and mining. -biomarkers, e.g. for body weight by connecting internal body fat distribution and clinical markers	The NuGO Association has performed pioneering work in the field of molecular nutrition, personalised nutrition, nutrigenomics and nutritional systems biology -NuGO Nutritional Phenotype Database (Van Ommen et al., 2010) -Initiatives that facilitate data sharing for nutrition biomarker search (e.g. ENPADASI.eu; European Nutritional Phenotype Assessment and Data Sharing Initiative) -BBMRI (Biobanking and Biomolecular Resources Research Infrastructure, see http://bbmri.eu)
Health – Determinants	Big-data on food purchase and consumer diets, among people that differ in health status and risk profile	Socio-demographic and lifestyle-determinants of food choice	Personalized advice on nutrition and well-being, e.g., Quisper/Qualify (http://www.qualify-fp7.eu/qualify-server-platform) and FoodNexus projects (http://www.foodnexus.eu/wp-content/uploads/2017/04/Factsheet_FoodNexus_Food-Wellbeing-platform.pdf) Intervention programs to combat childhood obesity (http://cordis.europa.eu/news/rcn/140055_en.html)

529

530 **Conflicts of interest**

531 None.

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579 **Appendix A**

580 Short description of the RIs and RI related activities described in figure 1.

581

Name	Description
ESS	European social survey, RI in the domain of social sciences (ERIC status)
CESSDA	European Social Science data Archives, brings together data archives (ERIC status)
Biomedbridges	Joint effort of twelve biomedical sciences research infrastructures on the ESFRI roadmap, RI in the domain of biology – medicine in Europe.
SHARE	Survey of Health, Ageing and Retirement in Europe, RI in the domain of economics, health (care) and social networks (ERIC status)
ECRIN	Clinical Research, supports multinational clinical trials (ERIC status)
EATRIS	European infrastructure for translational medicine (ERIC status)
BBMRI	Biobanking and BioMolecular resources RI (ERIC status)
Corbel	Collaborative scientific services for Biological and Medical (biomedical) RIs – including BBMRI, ECRIN, EATRIS, ELIXIR
MetaboHUB	National (French) RI in metabolomics & fluxomics (systems biology) for academics and non-academics in the fields of nutrition, health, agriculture and biotechnology
EMBL-EBI	The European Bioinformatics Institute, data sharing RI in the field of life science experiments (biology)
ELIXIR	RI in the area of life sciences; biological data platform, software etc.
RICHFIELDS	Project that aims to build a RI on Consumer Health and Food Intake for E-science with Linked Data Sharing
GloboDiet	Initiative that aims to develop and validate a standardized method for dietary assessments and provide the tools, support, and training for implementation
EuroFIR	Non-profit association that aims to support data use and collection of food composition tables.
ENPADASI	Nutritional Phenotype Assessment and Data Sharing Initiative. Joint action that facilitates data sharing for nutrition biomarker search. European
DEDIPAC	Determinants of Diet and Physical Activity. JPI project, started methodology mapping and research community building in the field of determinants of diet and physical activity
FOODBALL	Joint Action (JPI HDHL Biomarkers in Nutrition and Health) connecting several EU and national dietary intervention study to identify biomarkers of food intake
EURRECA	FP6 project that has identified and developed methodologies to standardise the process of setting micronutrient dietary reference values
NuGO	Association, RI in the area of molecular nutrition, personalised nutrition, nutrigenomics and nutritional systems biology
FOODSECURE	FP7 funded project. An interdisciplinary research project to explore the future of global food and nutrition security
SUSFANS	Metrics, Models and Foresight for European SUSTainable Food And Nutrition Security. H2020 project on healthy and sustainable diets from an nutritional and economic perspective.
EPIC	The European Prospective Investigation into Cancer and Nutrition study (IARC-WHO). Large cohort, epidemiological study on relationships between diet, nutritional status, lifestyle and environmental factors, and the incidence of cancer and other chronic

diseases.

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Figure 1

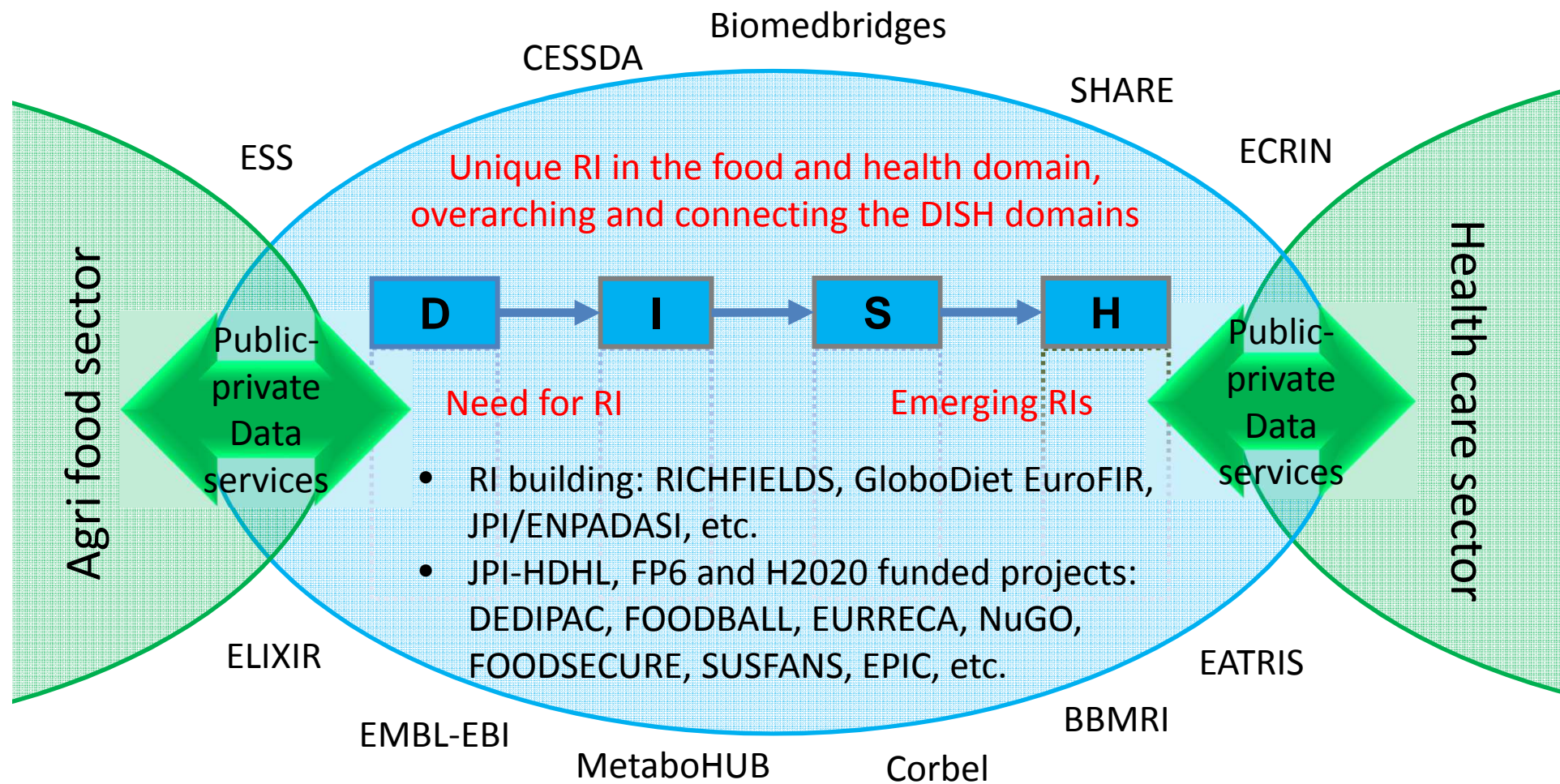


Figure 2

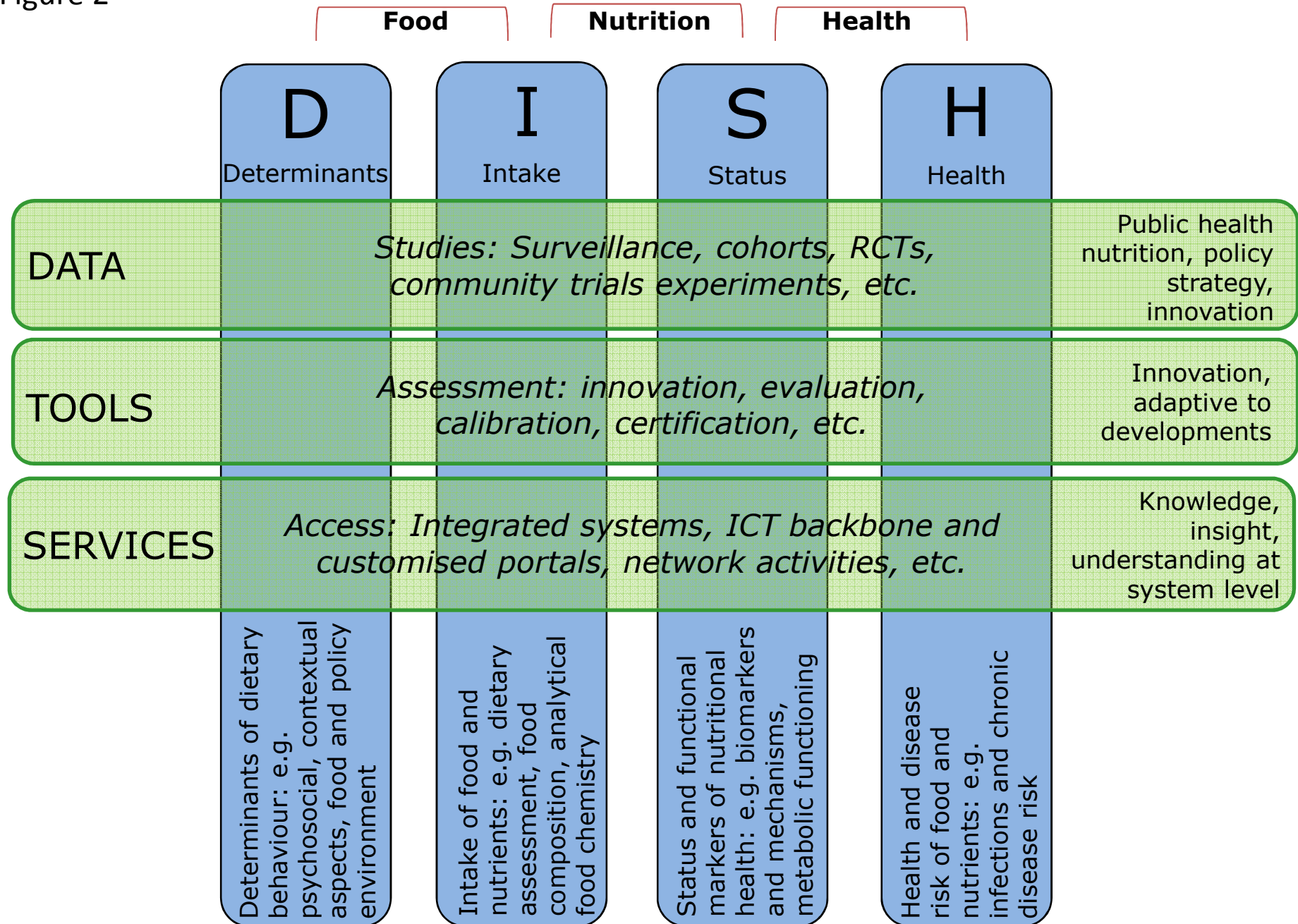
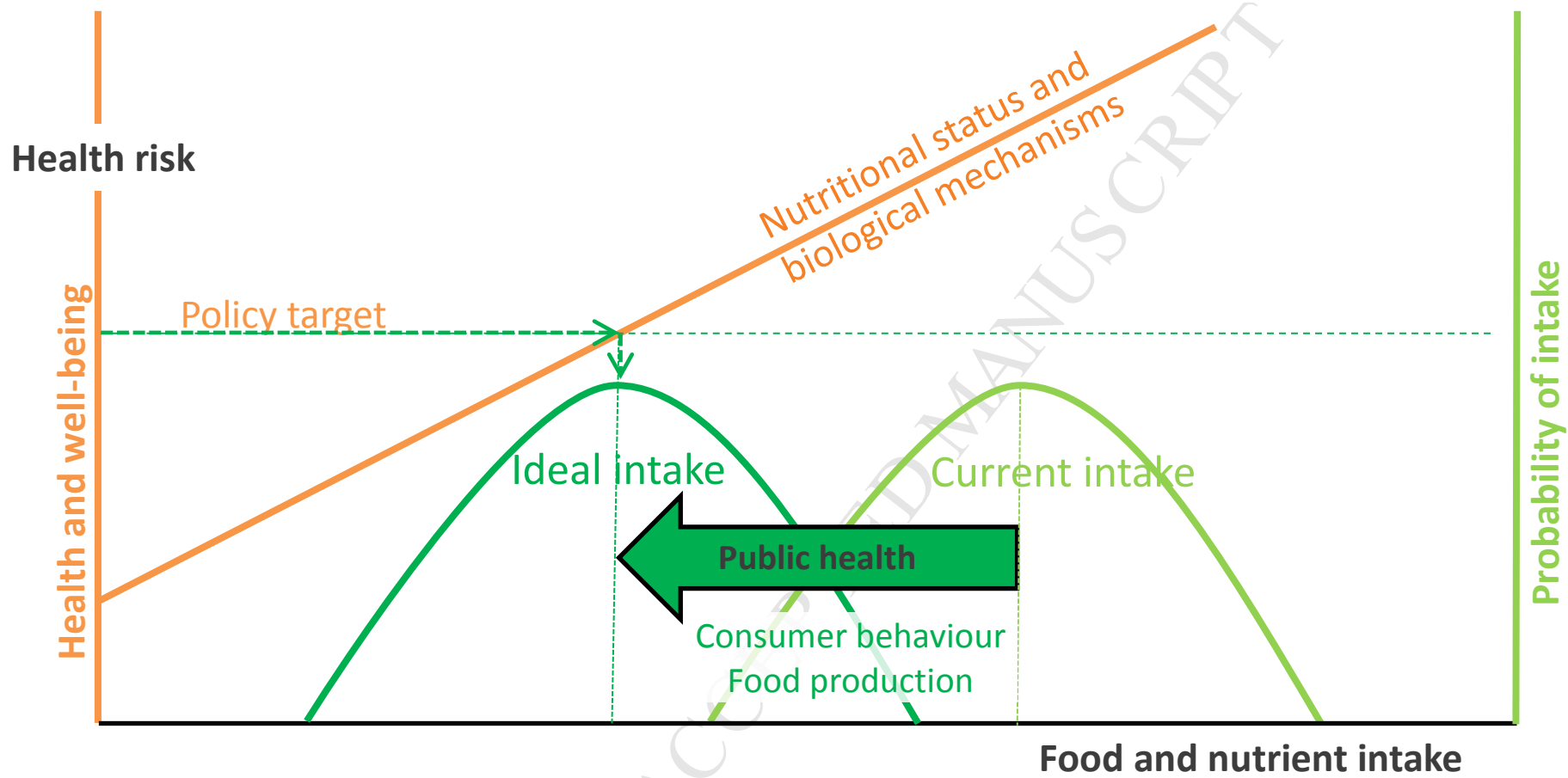


Figure 3



Advancing food, nutrition and health research in Europe by connecting and building research infrastructures in a DISH-RI: Results of the *EuroDISH* project

Highlights

1. EuroDISH showed the need for a unique, overarching RI in the food & health domain
2. The RI should connect countries and research disciplines, and build on existing RIs
3. It should provide **services** that facilitate research network and community building
4. It should provide access to standardised, interoperable, innovative **data** and **tools**
5. And, it should serve researchers, policy makers, industry, and societal stakeholders