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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: ***D****eterminants* of food choice, ***I****ntake* of foods and nutrients, ***S****tatus* and functional markers of nutritional health, and ***H****ealth* 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.

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

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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.

Key words

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

Introduction

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

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

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

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

In order to get insights in RIs in the food, nutrition, and health area, the EuroDISH project (http://eurodish.eu) mapped the existing RIs in Europe, identified gaps, and defined needs (Snoek et al., submitted). Then, in this project the results were synthesised into a conceptual design of what is needed to fully support future research in the field, and outlined in a roadmap on how to achieve this. A main conclusion was that there are needs for developing and strengthening RIs in each of the research fields on ***D****eterminants* of food choice, ***I****ntake* of foods and nutrients, its relation to ***S****tatus* and functional markers of nutritional health, and ***H****ealth* and disease risk (DISH model). Additionally, the project identified a unique need for a research infrastructure (a DISH-RI) that overarches these fragmented research domains and the domain-specific RIs. This paper elaborates on the results of the EuroDISH project and describes the characteristics and added value of a proposed *pan-European DISH-RI*. We also discuss how generation of a knowledge leap in the food, nutrition and health area will empower innovative research and public health nutrition (PHN) strategies to contribute more effectively in addressing societal challenges.

Approach

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

DISH-RI in the European research landscape

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

Established and emerging RIs within the DISH domains

EuroDISH mapping showed that a substantial number of food and health specific RIs were already emerging in the Status and Health domains, and to a lesser extent in the Intake domain. For the Determinants domain this was, however, less evident (Brown et al, submitted). To further demonstrate possibilities, advancements, and gaps of current RIs, two case studies were conducted for the Intake, Status and Health domains. Case study one followed the development of a dietary surveillance RI, specific to the Intake domain, yet also relevant to all DISH domains. The aim was to advance the software that is used to connect food composition databases. The non-profit association EuroFIR (eurofir.org) offers a food composition data platform and software (based on formerly EPIC-Soft) for collecting standardised food consumption data. This work is continued as the global nutrition surveillance initiative (GloboDiet) by the international agency for research on cancer – World Health Organisation (IARC-WHO). GloboDiet aims to develop and validate a standardized method for dietary assessments and provide the tools, support, and training for implementation. Case study two followed the development of a nutritional phenotype RI, connecting the status and health domains. This case study built upon work conducted previously by NuGO-network partners. NuGo (nugo.org) is an association of universities and research institutes that among other goals aims to shape a nutrition bioinformatics structure and as part of that offers a Nutritional Phenotype database (dbNP.org) to capture study data and metadata. This collective work has now been incorporated into the Joint Action ENPADASI (European Nutritional Phenotype Assessment and Data Sharing Initiative), funded by the Joint program initiative healthy diet for a healthy life of the EC (JPI-HDHL, healthydietforhealthylife.eu). In addition to the tools mentioned in the case studies, EuroDISH partners have driven the development of a Determinants and Intake relevant RI via contributions to the H2020-funded RI-design project RICHFIELDS (richfields.eu) that aims to develop an infrastructure of linked open data on consumer behaviour relevant to food, nutrition, and health.

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

Initiatives and RIs outside the DISH domains

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

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

Research agenda setting and funding

Eventually, the DISH-RI is envisioned to serve the research needs and advance the food, nutrition, and health research community, while the research itself is funded by national, European or global mechanisms and public or private bodies. Since RIs act as a research facilitator and not as a data owner, the DISH-RI can become an instrumental research platform for food, nutrition, and health topics. Such a platform can provide unique possibilities for improved interactions between the food production area, food industry and nutritional and health research. Similarly, DISH-RI can provide data and services to support development of policy strategies by international or national funding organisations and authoritative bodies. Examples of these are UN organisations (such as WHO, FAO, World Food Council) EC organisations (such as EFSA), disease specific organisations (such as the World Cancer Research Fund), and semi-private organisations (such as the Gates Foundation). Within this context, DISH-RI can benefit from synergies with the JPI-HDHL. JPI-HDHL has already established an organisational structure involving many countries and raising supporting research funding for food, nutrition, and health related topics.

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

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

Data

Connecting data over the DISH: opportunities for public health policies

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

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

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

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

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

Data enrichment, public and private stakeholders

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

Future perspectives

The challenges of data linkage and sharing over the width of the food, nutrition, and health area are enormous. For currently existing data, post-hoc standardisation and calibration are challenging. In the future, the extension to big data, and more diverse and in part imprecise data poses even more challenges. But, big data also offers many opportunities for research in all domains. For instance, data that is collected through apps on smartphones and so-called wearable technology (smartwatches, intelligent clothing) offers new perspectives. DISH-RI could enable researchers to take advantage of these developments by bringing together ongoing initiatives in the DISH domains. A related development is the shift from expensive data collection targeted to a specific research project, to or in combination with more cost-efficient use of existing data. Data quality remains an issue, even with individual data analysis, and could for example be secured in a shared tool for data quality appraisal. Finally, currently dominant methods of systematic literature review and traditional plain meta-analyses of aggregated data are expected to shift towards systematic querying of studies based on metadata followed by additional integrative analyses of their resulting data or selected subsets thereof.

Tools

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

Why do people eat what they eat?

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

What do people eat?

Classic dietary assessment methods of what people eat capture daily patterns in food intake e.g., Dietary Histories, 24h recalls and food records. They have evolved into widely employed Food Frequency Questionnaires in epidemiology and (replicated) 24h recalls in nutrition surveillance. Opportunities here are standardisation of dietary assessment and food composition and the link between them. New technologies are now becoming available via world wide web or mobile application based technologies (e.g. ASA24, a self-administered 24 hour recall; see https://epi.grants.cancer.gov/asa24/) or via ICT-based recording technologies of traditional assessment methods (e.g. app based prompts). Opportunities here are to improve measurement error, low response, and response bias. Tools for the assessment of eating habits may increasingly also be based on biomarkers. These are derived from the field of X-omics, such as metabolomics and nutrigenomics, and developed towards targeted indicators of specific foods. This was done for example in the projects JPI-FOODBALL, JPI-MIRDIET, and BIOCLAIMS that explored, identified and validated biomarkers related to nutrition. Such functional markers can serve to evaluate population health and nutritional needs. This was done for example by the EURRECA project to set micronutrient dietary reference values (Van 't Veer et al., 2013).

How does it affect health?

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

Beyond the data and tools: systems approach

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

Services

Services are the things that the research community can get and/or “buy” from the RI such as access to datasets, data processing procedures or attending training courses. A DISH-RI should provide technical services to make data and tools accessible for researchers and stakeholders. Technological and communicational services that support community building and networking are required for active interaction between all stakeholders in the field. In addition, dissemination and implementation of common standards, procedures and protocols can be facilitated through capacity building and training. Finally, to ensure smooth operation, both the DISH-RI itself and the services it offers have to be organised in terms of governance.

Technical services

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

Capacity building, training

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

Community building and networking

Network services facilitate researchers within and between the different domains in working together and exchange knowledge (e.g. conferences). This requires network-related and community building elements that allow for integration of research communities within and between the different research areas. This could be done by establishing centres of excellence and connecting these into an expert network. Such (virtual) expert centres can develop transnational and multidisciplinary collaboration in research projects, agenda setting, and funding. They can also provide tools and training for using these tools. Moreover, the research community can benefit from the research outcomes that have emerged from earlier successful (pan-EU) projects, joint-initiatives, and joint agenda setting. An example is the JPI-HDHL funded Joint Action ENPADASI that facilitates data sharing for nutrition biomarker research. Another example is the WHO-IARC Globodiet Initiative that aims to advance pan-EU nutrition surveillance by using standardised approaches and interfacing and upgrading the GloboDiet and EuroFIR research infrastructures. A final example is the Micronutrient Genomics Project portal with biological pathways for many micronutrients.

Governance

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

Discussion of future perspectives

Starting point, summary of main EuroDISH outcomes

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**. Connection of **data** over the DISH would enable analyses and modelling at a systems level. Other issues related to data are connections to other areas (e.g. food safety or sustainability), data enrichment by public and private stakeholders (e.g. food industry), and future developments such as big data, wearable tech, and joint initiatives. Connecting data requires standards for **tools** (measurement instruments, study design and computational methods), post-hoc standardisation, calibration of future tools to the existing ones, and setting technological standards. An ICT backbone supporting the interoperability and quality management of data and tools is an indispensable **service** for the research community to actually benefit from the RI. Other technical and network services include customised portals for different users and network services such as centres of excellence, capacity building and training, and joint agenda setting. Governance services are needed to organise the access to data and tools in terms of membership, ownership, privacy, and trust. Additionally, the governance of the RI itself should organise the centralised and distributed activities and enable flexibility regarding innovation.

Reflection on strengths and limitations of the EuroDISH project

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

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

Roadmap and timeframe

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

Next steps

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

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

Business model

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

DISH-RI as facilitator of pan-European interdisciplinary research

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

Conclusion

The EuroDISH-project clearly showed that food and health research could be advanced by a distributed and/or virtual RI to connect existing RI and research activities. An overarching DISH-RI was considered necessary to facilitate access to (yet un)available i) 'data' that could span across different studies, countries, disciplines and DISH research areas; ii) 'tools' to generate and exploit data such as standardised, harmonised, innovative instruments and methodologies; iii) 'services' to facilitate the scientific research community and other societal stakeholders to access the data and tools. This will also allow for addressing today's societal challenges on public health nutrition strategies (e.g., behaviour change, food reformulation), food and nutrition security (e.g., agricultural food supply, nutrition requirements and dietary guidelines) and innovative food and health research (e.g., big data, personalised nutrition, applying a systems approach). Added value could also be created in public-private partnerships by unlocking data and enabling valorisation of research insights in practice. 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.

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Figure captions

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

Figure 2. Conceptual design of EuroDISH outcomes on needs for RIs in the Food and Health research area. Columns represent and describe the DISH domains: ***D****eterminants* of food choice, ***I****ntake* of foods and nutrients, ***S****tatus* and functional markers of nutritional health, and ***H****ealth* and disease risk. Rows represent the data, tools and services that a DISH-RI should provide to achieve the scientific and societal impact described at the right side of the rows.

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

Table

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

Conflicts of interest

None.

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Sheehan Mark, Wicks Paul, Tasioulas John, Research led by participants: a new social contract for a new kind of research. 1015. J Med Ethics. Mar 30. pii: medethics-2015-102663;

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Appendix A

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

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 BBMIR, 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.

Figure 1

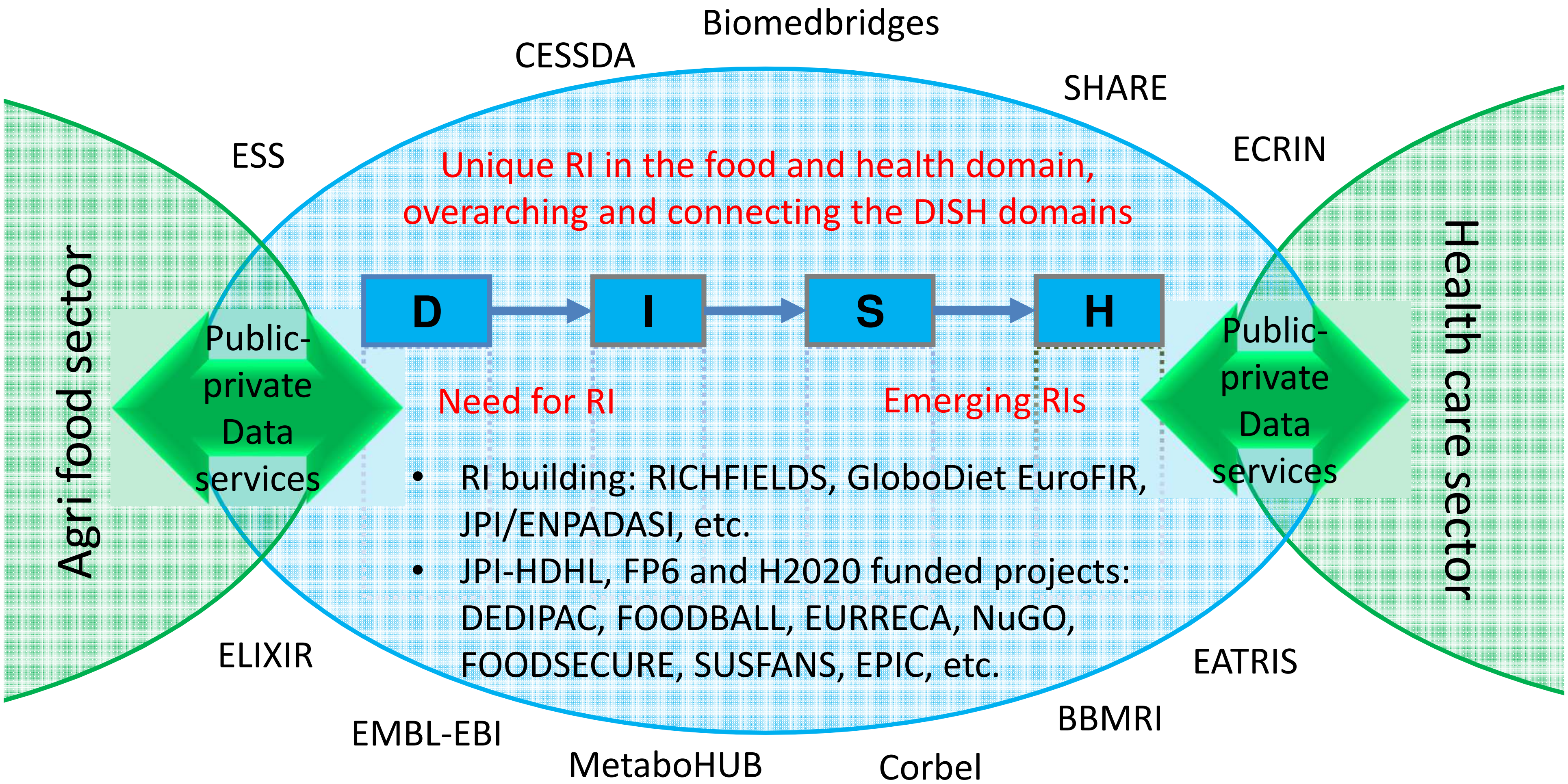

Biomedbridges
CESSDA
SHARE
ESS
ECRIN
Unique RI in the food and health domain,
overarching and connecting the DISH domains
Agri food sector
Health care sector
D
I
S
H
Public-private Data services
Public-private Data services
Need for RI
Emerging RIs
• RI building: RICHFIELDS, GloboDiet EuroFIR, JPI/ENPADASI, etc.
• JPI-HDHL, FP6 and H2020 funded projects: DEDIPAC, FOODBALL, EURRECA, NuGO, FOODSECURE, SUSFANS, EPIC, etc.
ELIXIR
EATRIS
BBMRI
EMBL-EBI
MetaboHUB
Corbel

Figure 2

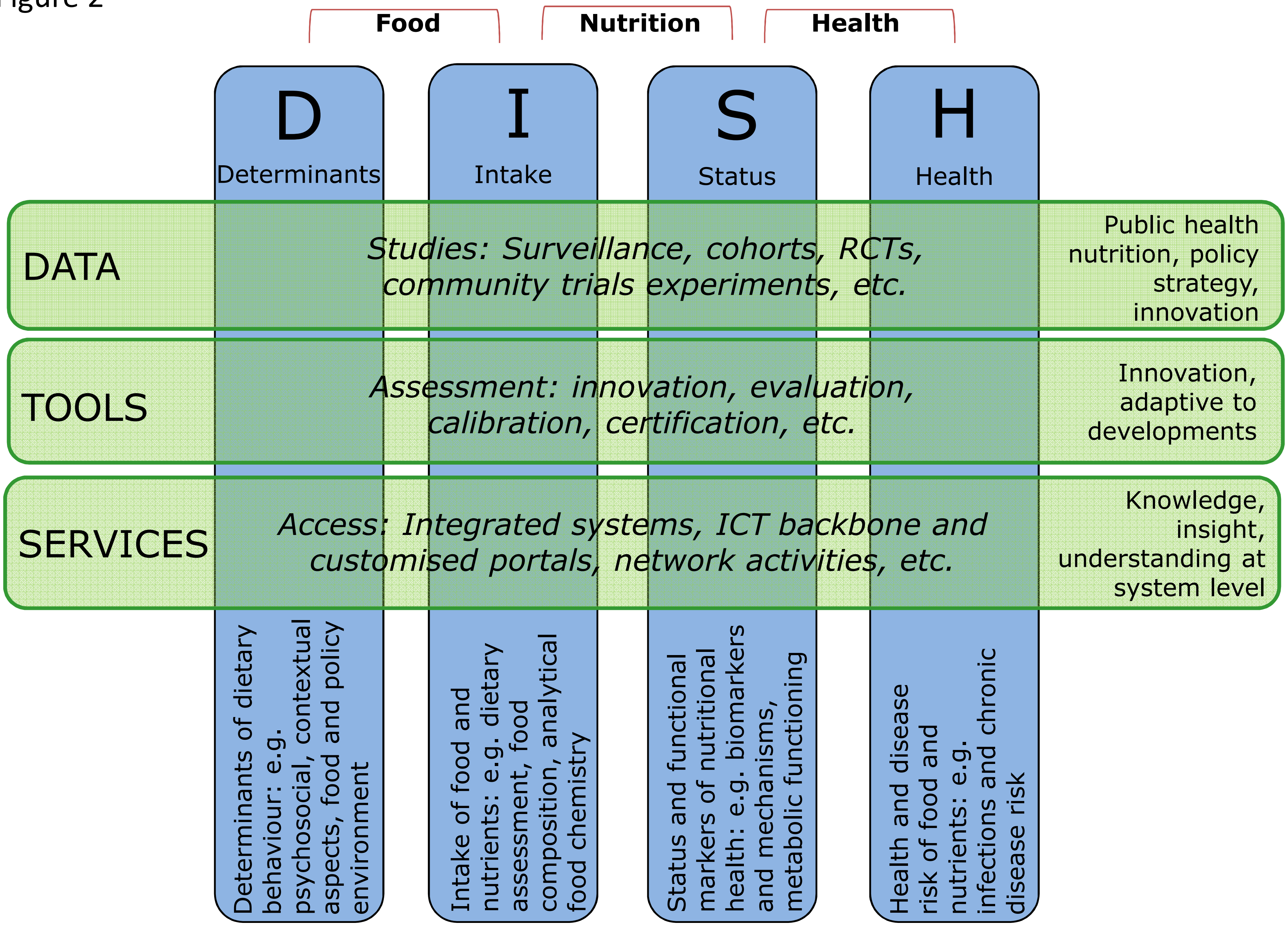
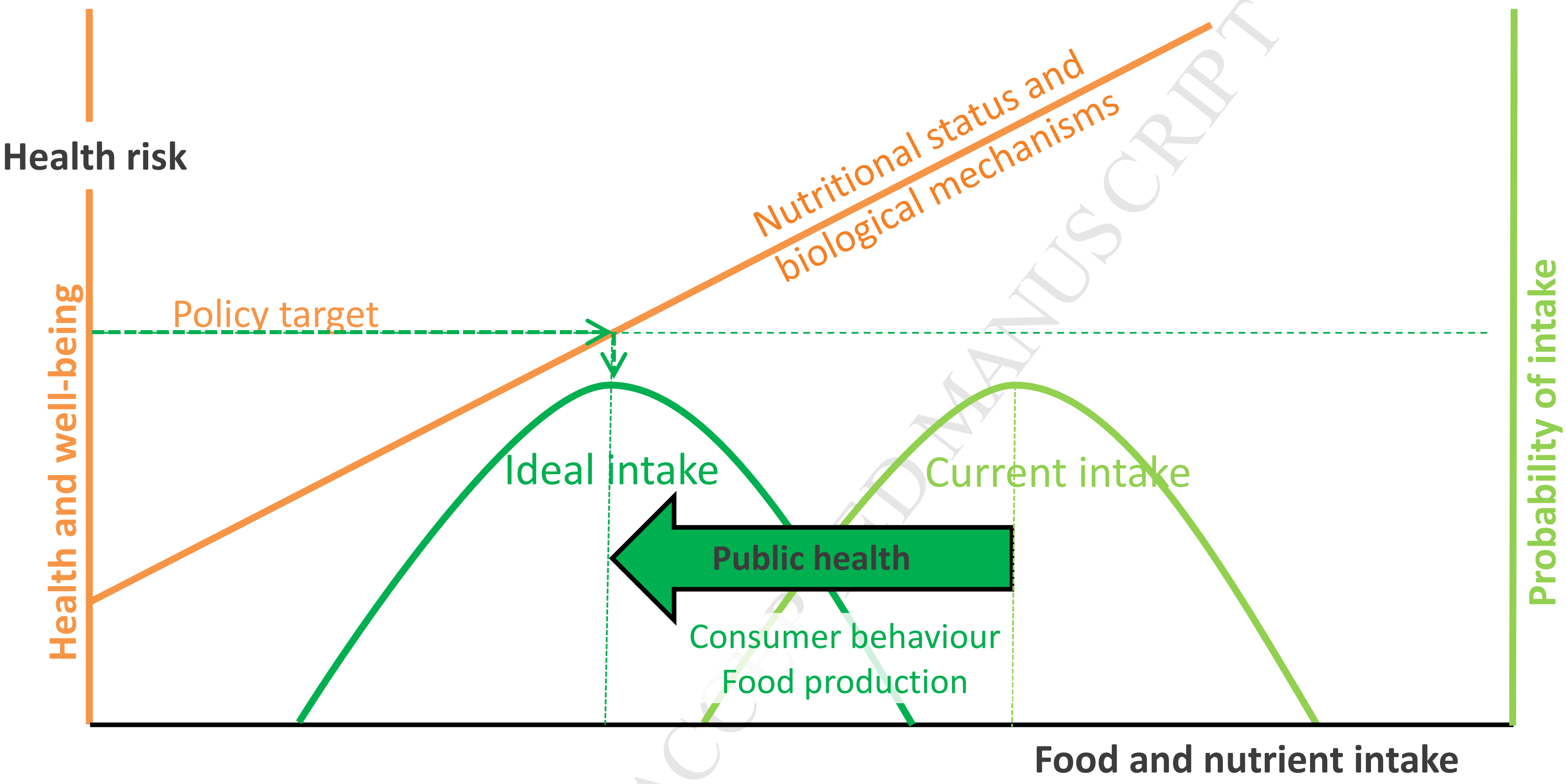

Food
Nutrition
Health
D
Determinants
I
Intake
S
Status
H
Health
DATA
Studies: Surveillance, cohorts, RCTs, community trials experiments, etc.
Public health nutrition, policy strategy, innovation
TOOLS
Assessment: innovation, evaluation, calibration, certification, etc.
Innovation, adaptive to developments
SERVICES
Access: Integrated systems, ICT backbone and customised portals, network activities, etc.
Knowledge, insight, understanding at system level
Determinants of dietary behaviour: e.g. psychosocial, contextual aspects, food and policy environment
Intake of food and nutrients: e.g. dietary assessment, food composition, analytical food chemistry
Status and functional markers of nutritional health: e.g. biomarkers and mechanisms, metabolic functioning
Health and disease risk of food and nutrients: e.g. infections and chronic disease risk

Figure 3


Health risk
Health and well-being
Nutritional status and biological mechanisms
Policy target
Ideal intake
Current intake
Public health
Consumer behaviour
Food production
Probability of intake
Food and nutrient intake

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