Food and Agriculture Organization of the United Nations

Social network analysis for territorial assessment and mapping of Food Security and Nutrition Systems (FSNS)

A methodological approach

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The paper is the result of the collaborative work of Vito Cistulli, Senior Policy Officer (FAO), team leader and co-author of the paper; Laura Prota, Assistant Professor of Economics, Program in International Relations at The American University of Rome (AUR), Italy; and Ivan Cucco, Adjunct Faculty, Graduate School, The American University of Rome (AUR), Italy.

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Executive summary

Food systems are complex systems that depend on a range of interacting socio-economic, cultural and environmental factors, all of which have a strong geographic dimension. To capture the spatial dimension of food insecurity we need to know how food systems work, and what the determinants of food security and nutrition level are in a given place and time. For example, where people do not have access to quality public services (e.g., water, energy, sanitation, schools), markets or decent work; and where people are unable to engage in political decision-making processes they are at risk of food and nutrition security (Nordin *et al.*, 2013). We also need to know who benefits and who loses in the food systems, who takes decisions and who influences decisions about the various dimensions of food systems, what are the actual decisions taken to address the various dimensions of food systems and how are they made. Answers to these questions can hardly be given with standard linear[1] and sectoral approaches.

Management of food systems should acknowledge the interplay of all these factors as well as of the actors involved who altogether influence the food landscape but individually they influence each other. As stressed by Young *et al.* (2008) "interplay occurs when the operation of one set of institutional arrangements affects the results of another or others". Understanding the linkages between actors is an important prerequisite to improving the inclusiveness and governance efficiency of food systems for it allows actors to establish strategic links between institutions to pursue individual or collective goals (Young 2002).

Relational methodologies such as complex systems and social network analysis (SNA) in particular provide a suitable framework to understand the multidimensional nature of food security and nutrition (FSN) as well as the interplay of actors.

1 Linearity is defined here as an analytical approach based on three assumptions: i) a systems' response is proportional to the causes affecting it; ii) comparing two situations that are identical except for one variable, the effect of that variable on the system can be isolated holding all other things constant; iii) the possibility to break down systems into components, the relationships of which can be analyzed separately, and the computation of the whole equals the sum of the relationships of the parts.

These approaches and their analytical tools[2] have been widely used in many areas, including sociology, economics, information, technology, biology, etc.

For its strong empirical focus, over the last decades SNA has grown in popularity because as noted by Hidalgo (2010) actors should not be seen only as a collection of individuals or organizations but also as networks of individuals and organizations who "interact sometimes through hierarchies, but mostly, despite them". In other words Hidalgo suggests that the way how actors interact (actual behaviour as opposed to assumed behaviour) is as important as the individual capacity or talent to explain success and failure.

Recently SNA has emerged as a key tool for understanding also the spatial patterns and social and governance aspects of Food Security and Nutrition Systems (FSNS) related issues. Over the last decade the number of publications and research work on the application of SNA to FSNS related fields has increased dramatically, thus reflecting the raising awareness of the instrumental role of social and institutional relations, often informal, in food systems management and governance.

(In)formal networks of actors and their groups, leaders, agencies, services and knowledge providers, etc., are key in trust building and conflict resolution, information diffusion, innovation adoption, resource mobilization, and ultimately in sustainable management and governance of food systems. Furthermore, there is general consensus that the increasing volatility, complexity, uncertainty and rapidity of changes of the context within which socio-economic systems in general and food systems in particular evolve cannot be fully captured and understood using mechanistic analytical approaches.

The innovation of the proposed application of SNA to FSNS lies therefore in the capacity of this method to:

- Set a clear distinction between the notion of markets and transactions in terms of exchange of products, labour, services and the notion of markets in terms of the embedded knowledge (both tacit and explicit) and the means they provide to make available the "knowledge that is held by few to reach many" (Hausmann *et al.* 2013)

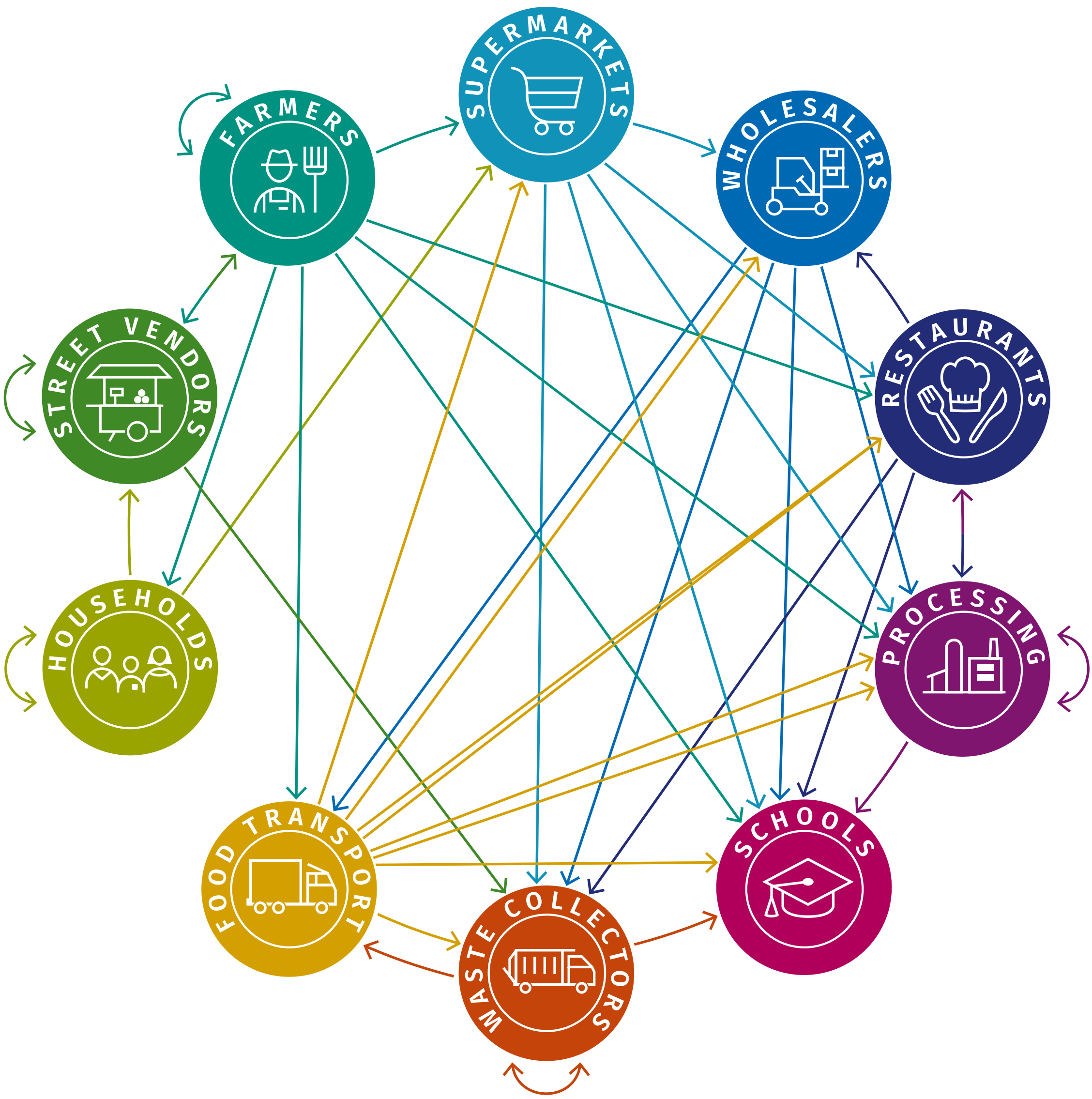
2 The most popular tools used in complex system analysis and SNA include Exponential Random Graph (ERGM), blockmodelling and community detection algorithms, Agent Based Simulation Modelling (ABSM) and Systems Dynamics (SD).

- Allow for an integrated and comprehensive analysis of FSNS based on a multi-relational networks analysis of the interactions taking place in people movements (e.g., migrations, commuting), exchanges of goods (e.g., food, inputs, etc.), and provision of services (e.g., remittances, credit, advice, information, etc.);
- Combine qualitative and quantitative analysis, through which complementary insights can be gained.
- Identify the geographic factors influencing the above mentioned interactions (e.g., remoteness, infrastructure, natural resources, basic services, markets, etc.);
- Visualize the territorial patterns of FSNS on geo-spatial maps;
- Apply participatory approaches in the development and analysis of SNA-FSNS networks.

Policy related issues that this method can address include but are not limited to: territorial agglomerations/isolation of food systems, closeness/openness, core/periphery, cohesion/fragmentation, market failures (monopolistic situations, information asymmetry, etc.), power relations, efficiency, and sustainability issues (e.g., gas emissions, health, etc.). SNA also provides a useful tool to build scenarios to assess the effects of alternative policies on the configuration of the food systems as a whole.

This work is part of a broader effort of FAO to support countries to improving the inclusiveness and sustainability of FSNS. It aims to build on, contribute to and complement other FAO work streams in this area, notably the work conducted on food systems and nutrition indicators, the city-region food systems, the rural-urban linkages, as well as the FAO initiative on territorial approach to food security and nutrition policy.

It is also the first attempt to develop a methodological approach able to analyse the social, institutional and economic dimensions of food systems and their relationships with food security and nutrition outcomes, as well as to assess the spatial patterns of food systems. From this perspective it should therefore be considered as a living document subject to further elaborations and improvements resulting from the empirical studies and evidence.



SUPERMARKETS
FARMERS
WHOLESALERS
STREET VENDORS
RESTAURANTS
HOUSEHOLDS
PROCESSING
FOOD TRANSPORT
SCHOOLS
WASTE COLLECTORS

1 Introduction

Approximately 3 billion people across the globe have low-quality diets according to the Global Panel on Agriculture and Food Systems for Nutrition (2016). FAO estimates that more than 800 million people suffer from chronic hunger (SOFI, 2017). World Health Organization (WHO), UNICEF, and the World Bank (2013) report that 161 million children under the age of five are stunted, and that 3.4 million people die each year due to overweight and obesity. The cost of malnutrition is estimated by FAO at about 3.5 trillion USD per year (FAO, 2013), that is slightly less than the total value of food and agribusiness in the world, estimated by McKinsey at 5 trillion USD. Moreover, the incidence of overweight and obesity is growing in every region. The situation is set to worsen dramatically over the next 20 years if powerful drivers of change such as population growth, climate change and urbanization, all converging on food systems, are not adequately addressed.

These trends are paralleled by increasing within-country disparities in both income and food security levels as well as levels of nutritional status. Food insecurity, malnutrition in all its forms, poverty and geographic disparities in low income countries are strongly correlated. This has important policy implications for if undernutrition, micronutrient deficiencies and overweight or obesity are unevenly distributed across the country so too are the types of interventions and costs of overcoming the problem of food insecurity and malnutrition in all its forms.

Understanding the root causes of the spatial and social diversity of food systems patterns is the main purpose of the methodology proposed. Differently from the existing literature, which has generally focused on parts of the food systems (i.e., innovation, diffusion and adoption, cluster analysis, etc.), the purpose and ambition of the proposed approach is to provide a framework for a comprehensive, integrated and geo-referenced assessment of all the factors that influence Food Security and Nutrition Systems (FSNS) patterns (social, economic, environmental and institutional). A special focus is placed on the role played by the social and institutional relations as well as by the individual actors' decision making behaviour in the food systems.

The following sections provide: i) an illustration of the actor-based FSNS concept and analytical framework with a special focus on its multidimensionality nature and spatial dimension; ii) a description of the step-by-step methodology for the application of Social Network Analysis (SNA) to FSNS systems; and iii) some concluding remarks. Finally this publication includes a glossary of terms used in SNA, which will help to introduce the reader to the technical language of SNA.

… every part is thought as owing its presence to the agency of all the remaining parts, and also as existing for the sake of the others and of the whole, that is as an instrument, or organ...

The part must be an organ producing the other parts — each, consequently, reciprocally producing the others...

The Critique of Judgment, Immanuel Kant, 1790

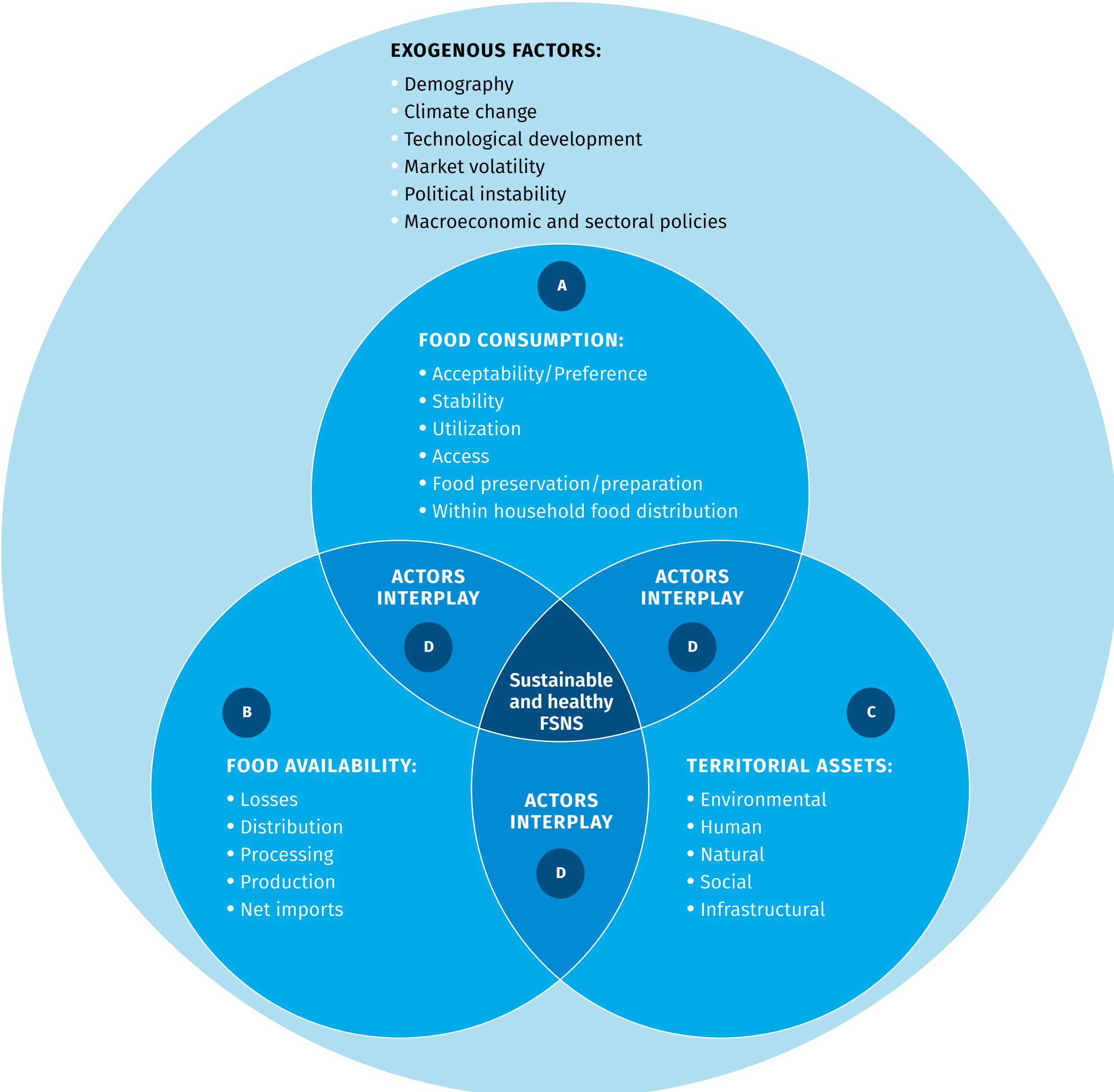
2 Food Security and Nutrition Systems (FSNS): a conceptual and analytical framework

Food systems are complex non-linear, multidimensional and heterogeneous networks of social, economic, institutional and environmental relations evolving over space and time. They are characterized and affected by webs of complex interactions - cutting across borders both within and between countries - and feedback loops, broad constellations of policies, as well as multi-scale power relations and the political economy. These features have strong consequences on the way policies should be conceived, and on the way how knowledge should be assembled and conveyed to inform them and policy action.

Many conceptual frameworks have been proposed to analyse food systems and their evolution[3]. The purpose of the framework (Figure 1) suggested in this paper is not to add a new one but rather to adapt and complement the existing ones by emphasizing the actors' and their collective actions' role in shaping the food systems, which in turn determine food security and nutritional outcomes of the population.

[3] A vast literature exists on the transformations of food systems and their conceptualization. The following references are just a sample of the many contributions that have been used to build the framework proposed in this report (Aragrande and Argenti, 2001; Maxwell and Slater 2003; Kennedy *et al.* 2004; Lang and Heasman, 2004; FAO, 2009 and 2012; Ingram 2009; Ericksen *et al.* 2007, 2008 and 2010; Reardon and Timmer, 2012; Dubbeling *et al.*, 2015), environmental changes such as decreasing water availability, input pollution and energy demand (Pretty *et al.*, 2005; Molden and Fraiture, 2004; Matson *et al.*, 1997), decline of farming in the value added generation of food systems (Boehljie, 1999; Hendrickson and Heffernan, 2002), globalization of value chains and the booming of supermarket (Pretty *et al.*, 2005; Reardon *et al.*, 2002); dietary transition and impacts on health (malnutrition) (Popkin and Gordon-Larsen, 2004), and urbanization (Kennedy *et al.*, 2004).

FIGURE 1: **Food Security and Nutrition Systems: a conceptual framework**



Following the precept according to which "food systems need to be harnessed so that they nourish rather than merely feed people" (GPAFSN 2016), the proposed framework (Figure 1) suggests that sustainable and healthy FSNS is the result of the interactions taking place between three categories of factors, namely:

- Food availability determined by the various stages of the supply chain, net imports, increasing competition of food production with non-food production, urban encroachment on agricultural land and environmental use of land;
- Food consumption resulting from access, stability, utilization and acceptability of foods (i.e., consumer demand shapes decisions on what foods to produce, process and trade. The main drivers of demand at household level are purchasing power and preferences. Individual food consumption is influenced by household food preservation, preparation and cooking practices, and intra-household distribution);
- The territorial assets which play a key role in the shaping of food systems patterns and their sustainability.

Figure 1 further highlights that these interactions are influenced by exogenous factors and mediated by the actors of the food systems. Actors use natural resources and environment to produce and dispose food wastes and losses, they distribute, consume, store food and they organize themselves in associations, organizations, etc. In brief, sustainable and healthy FSNS is the final outcome of a complex system of mutual influences between actors and their social, economic, policy, institutional and environmental contexts, which all have a strong spatial specificity. Therefore, a territorial approach to FSNS (Box 1) is proposed as a suitable framework to: i) understanding the role of territorial assets in influencing the FSNS dynamics; ii) mapping the geographic space within which the FSNS interactions take place; and iii) capturing the diversity of response capacity of specific spatial and socio-economic contexts to policy reforms and shocks.

Because of the diversity of interactions between territorial assets and the socio-economic actors (market exchange of goods, services, social and cultural relations, use of natural resources, etc.), very different results may be obtained, which establish a great variety of economic, political, and social situations. Yet, these various interactions are not systematically taken into account in food security and nutrition policy-making, thus resulting often times in a disjunction between the process of decision-making at the central level and the process by which decisions are implemented at the local level, as well as between the anticipated and actual outcomes of the strategies and policies.

Only recently, with the resumption of the concept of foodsheds (Hedden, 1929) and food catchments by the local food systems movements (Feagan, 2007; Freedman *et al.*, 2011), the notion of city regions food systems (FAO, 2015) and the promotion of a territorial approach to food security and nutrition policy (Cistulli *et al.*, 2014; OECD-FAO-UNCDF, 2016; Cistulli *et al.*, 2016) has the spatial dimension of food systems been brought back to have come back to the attention of practitioners and policy makers on global and national levels. This approach focusing on rural-urban linkages is also reflected in the New Urban Agenda endorsed by the United Nations in December 2016, which, in the shared vision, stresses that cities should "Fulfil their territorial functions across administrative boundaries and act as hubs and drivers for balanced, sustainable and integrated urban and territorial development at all levels".

As highlighted in Figure 1 and further specified in the definition of Box 2, Food Security and Nutrition (FSN) and food systems are intertwined and cannot be separated. Therefore, this paper argues that sustainable levels of FSN can be achieved only if food systems are effective from a social, environmental and economic perspective. Accordingly, in this report the two notions are combined in the concept of FSNS.

Against this backdrop, the closest and most relevant definition of food security and nutrition system adopted here is a combination of the definition suggested by FAO[4], FAO and UNEP[5] and Calgary[6], which provides a stronger actor perspective and key principles. The definition adopted is summarized in Box 2.

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4 FAO. 2013. The State of Food and Agriculture: Food systems for better nutrition. Rome. p.3 .

5 FAO-UNEP Sustainable Food Systems Programme; HLPE, 2014, Food Losses and Waste in the Context of Sustainable Food Systems, Report of the HLPE, Rome: HLPE available at http://www.fao.org/3/a-i3901e.pdf. References for further readings on the concept of sustainable food systems include Allen, 1993; Allen, 2004; Blay-Palmer, 2008; Hinrichs & Lyson, 2007; Nodin *et al.*, 2013, O'Riordan, 2001; Roling & Wagermakers, 1998; Blay-Palmer, 2010.

6 City Manager's Office, 2012, Definition of Food Systems, Calgary, Canada.

BOX 1

THE RATIONALE AND IMPORTANCE OF TERRITORIAL APPROACH TO FSNS

Territorial capital underpins the structure of local socio-economic systems and influences actors' behaviour (government, enterprises, households) and interactions. They also constitute the mediating factors (prism effect) through which the intended objectives of policy interventions or shocks are translated into actual outcomes and impacts (e.g., income increase, factor productivity increase, hunger reduction, elimination of malnutrition in all its forms, and poverty reduction). The territorial model suggests therefore that one-size-fits-all policies are not an option and that policies, actions, and public investments to address hunger and malnutrition should be based on a good understanding of how food systems work and on their spatial/territorial patterns.

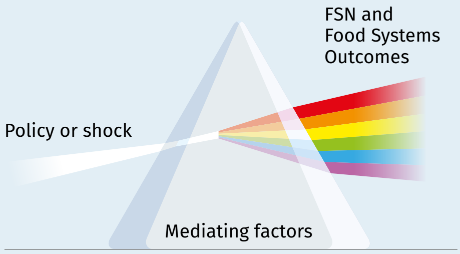
Territorial capital

- Natural, environmental and historical capital
- Human capital (know-how/skills)
- Infrastructure (e.g., roads, telecommunications, energy provisioning, irrigation and water management, storage capacity, etc.)
- Productive capital (productive sectors of the economy)
- Social capital (including social services, such as education, financial, insurance, etc.)
- Perception/image/cultural capital

Following the above description, the territorial space is defined as a geographic, social and economic sub-system of national space made up by assets and structural factors interacting (e.g., people buy and sell goods, they invest, they establish contracts and associations, etc.) within the sub-system, with other sub-systems in the country and with national and global systems. Its boundaries will vary depending on the type of intervention and objectives pursued, and its development path is determined by exogenous factors (factors beyond the control of the territorial space: e.g. natural and man caused hazards, political events, technological innovations; economic cycles), and endogenous factors (changes determined by targeted interventions including policies, advocacy, knowledge, financing).

Actors of food systems (examples)

The role of territorial capital (mediating factors)



BOX 2

DEFINITION OF FOOD SECURITY AND NUTRITION SYSTEM

The multi-dimensional nature of food systems is well reflected in the HLPE definition (HLPE 2014): "A food system gathers all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food and the outputs of these activities, including socio-economic and environmental outcomes".

Calgary City further adds some useful principles to guide policy makers and planners toward sustainable food systems: "Sustainable food system is a collaborative network that integrates several components in order to enhance a community's environmental, economic and social well-being. It is built on principles that further the ecological, social and economic values of a community and region (based on Pothukuchi, K. and Jufman, J.L., 1999)".

Principles

- Secure, reliable and resilient to change (including climate change, rising energy prices, etc.) And accessible and affordable to all members of society
- Energy efficient
- An economic generator for farmers, whole communities and regions
- Healthy and safe
- Environmentally beneficial or benign
- Uses creative water reclamation and conservation strategies for agricultural irrigation
- Adopts regionally-appropriate agricultural practices and crop choices
- Contributes to both community and ecological health
- Builds soil quality and farmland through the recycling of organic waste
- Supports multiple forms of urban as well as rural food production
- Ensures that food processing facilities are available to farmers and processors
- Celebrated through community events, markets, restaurants, etc.
- Preserves biodiversity in agro-ecosystems as well as in the crop selection
- Has a strong educational focus to create awareness of food and agricultural issues, and is fairly traded by providing a fair wage to producers and processors locally and abroad.

3 Applying Social Network Analysis (SNA) to the spatial assessment and mapping of FSNS

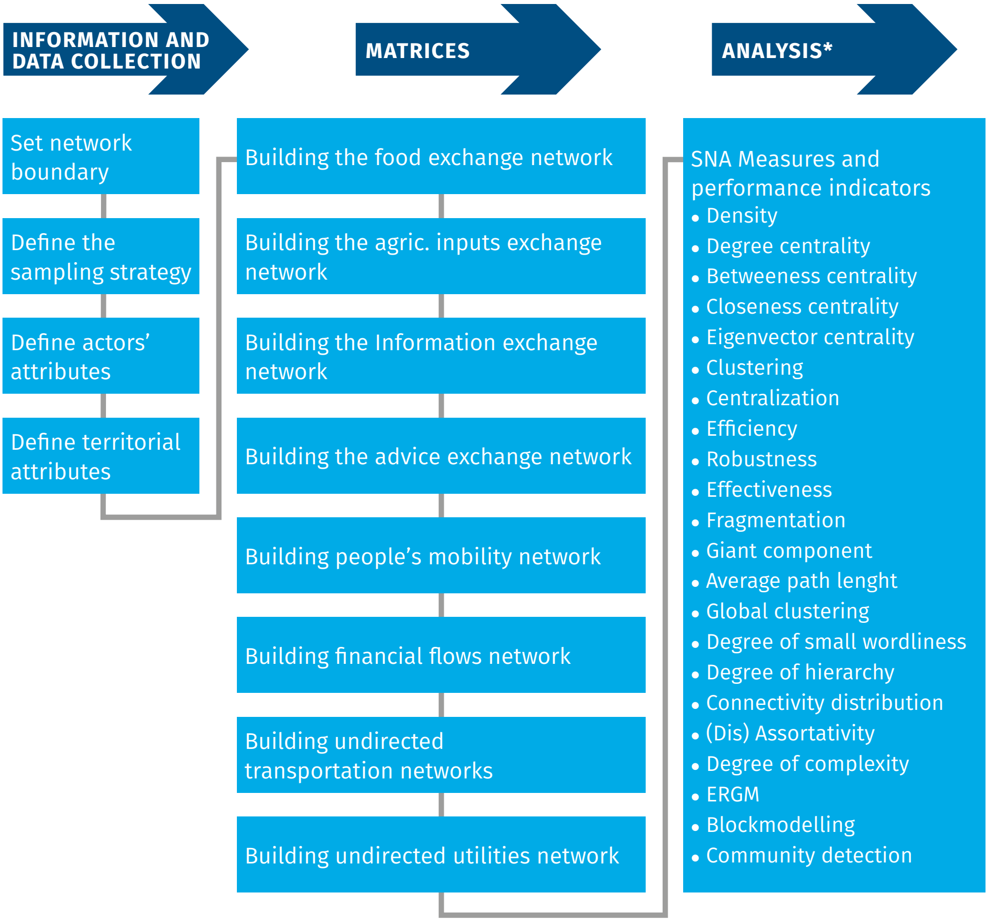
According to the conceptual framework illustrated in Figure 1, three broad layers of information systems are required:

1. Socio-economic information and attributes of the actors involved (area A and B);
2. Stock of capital endowment at the relevant geographic scale (area C);
3. Relations between actors and between actors and resources (area D).

Exogenous factors and policy effects are factored in as part of the relations between actors and resources, for they influence the behaviour of the actors in the use of the resources (Valente, 2012). Layers 1 and 2 will be informed by existing national statistics (Censuses, Income and Expenditure Survey (IES), General Household Survey (GHS), the National Food Consumption Survey (NFCS), Community surveys, Living Standards Measurement Study (LSMS), etc.), other existing information systems (infrastructure, location of urban areas, utilities, etc.).

Layer 3 may require additional information not provided by national statistics. This is the case, for instance, of nutrition-related knowledge, attitudes and practice or on the intra-household distribution of food. In this circumstance, complementary household survey may be needed.

FIGURE 2 **Step-by-step approach to the application of SNA to FSNS.**



Layer 3 is also based on direct surveys and information collection that will help build the relational networks. This information will be collected through direct interviews with actors, focus group discussions, and other relevant means.

* Definitions of the SNA measures are provided in the glossary of terms

In particular three broad categories of actors' interactions will be informed:

- **People movements**: people move from one place to another for a variety of reasons. Many migrants from rural areas move because of socio-economic factors, including poverty, food insecurity, lack of employment opportunities, limited access to social protection, and the adverse impacts of environmental degradation and climate change. Others are forced to migration due to conflict, violence, human-made crises and natural disasters. Migration movements differ in terms of distance (internal or international migration) and duration (permanent or temporary migration, including seasonal labour migration). Migration poses both challenges and opportunities (Deotti and Estruch, 2016) to local livelihoods, food security and nutrition and food systems. For example, migration of young people is a cause of ageing and feminization of rural population, which in turn is associated with lower productivity and innovation in agriculture and low income levels. On the other hand, through remittances and the transfer of know-how, technology and skills, migrants may support local investments including in agriculture, which will be translated in higher productivity, income and possibly in job creation. People also move, sometime covering long distances, to catch water and fuel for food preparation.
- **Commodities and goods exchange**: food, is bought, sold, processed, stored and wasted within the community, at the district, national and international level. The data gathered on exchange of goods and commodities will also inform on the places where exchanges take place and on the distances covered by the goods and commodities;
- **Service provision**: education, health, environment/climate change (pollution, erosion, floods, droughts, etc.), waste disposal, landscape, water, electricity, financial, information and communication, extension/support services (e.g., agricultural extension, veterinary services, etc.), transport/infrastructure, are supplied to and used by people. Their location and the time needed to access services impact differently on livelihoods and food systems.

The proposed SNA approach will capture all of these flows and exchanges in specific interaction networks that will be mapped using geo-referenced data.

Step 1: **Information and data collection**

Set network boundaries. The definition of the study area and population is of critical importance in network analysis as in most relational phenomena the exclusion of potentially important actors and/or relations can drive to misleading or erroneous conclusions (Laumann *et al.*, 1983; Wasserman and Faust, 1994; Scott, 2017). This decision entails establishing a rule to define the geographic and/or actors' boundaries of the network, that is who will be included in the study and who will not. In practice, the identification of the geographic area to start the research study is generally decided at the very beginning of the process. For example, the Government can be interested in understanding how inclusive are the food systems in an urban area or in a district of the urban area and what are the causes of exclusion of some groups (Ortolani *et al.*, 2017; Prota and Beresford, 2012). In this case the initial step of the network analysis would be to identify a census of key actors involved in a process. Subsequently, the selected actors will identify the other actors they are connected with in food systems related interactions and so on until there are no more connections. The final geographic coverage (foodshed or food catchment) will most probably be larger than the initial geographic area (urban area or district of an urban area) as some food systems actors such as, for example, wholesalers, processors, and producers can be located outside the city. It follows that the actual territorial area covered by the food systems is determined by the location of the actors involved in the food system analysed and by the density of the interactions. There are several approaches proposed in the literature to address the boundary problem in network analysis (Laumann *et al.*, 1983). The characterization of the actors and the final geographic area by their socio-economic attributes and physical attributes respectively is another important set of information that need to be collected to conduct correlation analyses between, for example food system patterns and food security and nutrition outcomes. This information is generally available in the standard socio-economic surveys or censuses conducted by the countries and do not therefore raise particular problems as long as they are also available at the local level.

Sampling strategy. After the identification of the boundary of the initial geographic area and the population of interest, the unit of analysis at which the network variable has to be measured and analysed will be identified. There are two broad approaches for gathering relational data:

- non-probability sampling such as respondent driven sampling (Goodman, 1961; Heckathorn, 1997 and 2002; Salganik and Heckathorn 2004; Gile and Handcock 2010);
- probability sampling, such as link-tracing sampling or ego-centric sampling.
- a census gathering information from the entire population not only about individual characteristics but also about the relations linking each unit with the other.

Respondent-driven sampling designs apply to situations where the size and boundaries of the sample are unknown and no standard sampling frame exists, which might also be the case of Food Security and Nutrition Systems (FSNS) actors and in particular of the informal actors (Handcock and Gile 2011; Gile and Handcock 2010). The techniques start with the selection of some focal actors within the process, either randomly or purposefully selected, which provide names of a number of other actors fulfilling the research objective on one or more selected relations. In turn these actors are approached by the surveyors and are asked to provide a number of names of other relevant actors. The process continues until a comprehensive coverage of the relevant population is reached and allows researchers to build the network of links. Respondents can either recall the names of their contacts (in a free recall survey) or select them from a list that is provided to them and compiled in advance by the research team. This list for instance can include the names of all the retailers in an urban area such as for example street vendors in a slum. This latter format is generally preferred when possible as it reduces the likelihood of missing data. However, in some cases this interview format is not feasible as the list of potential partners is too long or unknown. It is important that respondents are left free to name as many partners they want so to get an accurate measure of actors' centrality in the network.

Ego-centric sampling is preferred when the research focuses on a comparison of egos' relational neighbourhoods. In this ego-centric approach, a random sample (or a stratified sample) of actors is taken from the initial target population. Each respondent is asked to report on her relations and to indicate how her partners relate to each other. For example, a sample of street vendors can be interviewed to distinguish them on the basis of their customers and suppliers, as well as on their behaviour with regards to customers and suppliers. When a roster of customers and suppliers is obtained, the respondent is asked to indicate what types of relations link these named alters. Possible questions are, for example, do her more assiduous customers know each other? Do they also work together? Do they come all from the same area, or same ethnic group or family? Do her suppliers also serve other vendors in the area? Beyond mapping all the relations among alters, the respondent is also asked to inform on the attributes of each alter, including the occupation, gender, ethnic group, land ownership, etc. In some cases, but not always necessary, named people are interviewed to verify the information of the first respondent. Once a representative sample of these individual networks is obtained from the population, ego-networks can be compared one-another to find regular patterns. For instance, it is possible that network size and characteristics will change by respondent's income. Or that relational patterns can be explained by gender or race, or geographical location. Ego networks can further be analysed with statistical models to derive general characteristics of the populations (Snijders *et al.* 2010).

Finally, census data are generally preferred when the focus of the research is on the overall structure of the network and its topology. This third approach is particularly effective when the units of analysis are limited in number (such as for example 200 street vendors in a slum) or when archival data are available (as in the case of the road system linking cities within a region or the messages sent by members on a web-platform).

In brief, the sampling process allows the researcher to identify the relevant actors of the food system as well as their level of aggregation and organization. The actors can be individuals, households, farmers, traders, processors, retailers, their associations (farmer associations, trade unions, etc.), service providers (finance, extension, etc), and government institutions.

Define actors' and territorial attributes: the attributes of actors can be collected either through existing standard surveys, through ad hoc direct interviews with actors or indirectly through information provided by other actors (i.e., proxy respondents). Territorial attributes generally include information about infrastructure and transportation networks: water, electricity, roads, railways, airways, bus, public administration offices, clinics, schools, markets, retail shops, restaurants, etc. is provided by census or archival data. Other sources of information include national GIS maps and ICT platforms. The proposed analytical framework assumes that the territorial attributes can influence the levels of food security and malnutrition in many respects. For example, agro-ecological resource endowment, access to input and output markets, and availability of educational and health facilities all influence food security and nutrition levels of households.

At the end of the analysis it will be possible to profile respondent on the basis of their networks: some will have solid contacts extending to institutions, other regions etc; while others will have fragile and insecure ego-networks. This analysis is often associated to a measure of Social Capital (Burt 1992). An indicative set of attributes both of actors and geographical areas necessary to inform the network analysis is recapitulated in Table 1. There are however no limits to the attributes to be used.

TABLE 1 **Example of attributive information required**

	Example of Attributes
Households	Geo-localization
	Household consumption expenditure
	Food consumption expenditures (distinguished for the 5 different categories of food products)
	Amount of food production for self-consumption
	Undernourishment index, nutritional status
	N of household members and demography / dependency ratio
	Gender of household head; presence of both household heads
	Education levels (for head and members)
	Quality of dwelling and sanitation
	Assets owned (with focus on food storage and preparation)
	Person(s) responsible for food purchase and preparation
	Eating practices: meals in house, meals outside, family meals etc.
	Religion
	Occupations of household members
	Ethnicity
	Migration status / length of residence
	Others
Traders and retailers (e.g., street vendors, collective catering, wholesalers, food shops, super-markets, restaurants, etc.)	Geo-localization
	Category (street vendor / truck / stall / restaurant / etc.)
	Ownership (Private / state enterprise / collective-cooperative)
	Total income (sales) [disaggregate in turnover and profits]
	Income for (the different categories of) food
	Productive assets
	N. of employees
	Types of food provided
	Hours / seasonality
	Price of standard meal / main food served
	Turnover and profits
	Formal / informal
	Compliance with basic sanitary standards
	Others

Farmers	Geo-localization
	Total income (sales)
	Income for (the different categories of) food
	N of employees
	Others
Food processors	Geo-localization
	Ownership [Private / state / collective-cooperative]
	Total income (sales) [disaggregate in turnover and profits]
	Income for (the different categories of) food
	Productive assets
	Specialization
	N of employees
	Others
Service providers	Private / State companies / NGOs / INGOs, banks, local saving schemes, public transfers, etc.
	Formal or informal
	Geo-localization of the service delivered
	No. of employees
Organizations and institutions	Government administrative bodies, farmer associations, water associations, academia, research institutions, etc.
Roads	Roads' map and road conditions
	Geo-localization of crossroads
Railways	Railways map and schedule
	Geo-localization of stations
Buses	Buses map and schedule
	Geo-localization of stations
Hospitals	Geo-localization
	Size in terms of employees
	Size in terms of patients
Schools (distinguishing primary, secondary, and higher education)	Geo-localization
	Size in terms of students
Local institutions (religious, unions, farmer associations, etc.)	Geo-localization
Public administration offices (different than education institutions and hospitals)	Geo-localization
Police offices	Geo-localization
Financial services providers	Geo-localization
Water sources (distinguishing by use: house, irrigation, and environment)	Geo-localization

Step 2: **Building matrices and network graphs**

Territorial, undirected networks and actors' exchange matrices are built in a participatory manner. These include the network of transportation infrastructure, which is used to build the geo-distance matrix, and the network of utilities (water, energy, etc.). These maps are complemented by the territorial attributes such as the localization of schools, health centres, sources of water, etc. Actors' exchange networks are generally directed. For example, for food exchanged in one direction (from seller to buyer), there will be money exchanged in the other direction (from buyer to seller). This is not the case of transportation networks as the unit of exchange is the same in the two directions (e.g., distance, time, fare, etc.). In total this application proposes 9 1-mode categories of networks highlighted in Table 2 (I, U, FE, AI, IE, AE, PM, FF, AM), each one of which is comprised of sub-networks, the number of which will depend on the research study. In this application we propose 35 sub-categories (see column (B) of Table 2). Depending on the findings of the field work and principal component analysis, the selection of the sub-categories may be further refined. In addition, all the networks of the 9 categories are 1-mode networks (column (E) of Table 2). Two undirected affiliation 2-Mode networks (SP, WS), are also proposed. Finally, all the networks are weighted with a specific metrics (column (F) of Table 2).

TABLE 2 **Categories of network matrices**

MATRIX CODE (A)	NETWORK (B)	DIRECTEDNESS (C)	WEIGHTS (VALUED) (D)	1- OR 2-MODE (E)	METRICS (F)
I	Infrastructure Network				
I1	Roads network	NO	YES	1-mode	Travelling time or ED
I2	Railways network	NO	YES	1-mode	Travelling time or ED
I3	Water network	NO	YES	1-mode	Travelling time or ED
I4	Air network	NO	YES	1-mode	ED
U	Utilities				
U1	Potable water network	NO			ED/REL
U2	Electricity network	NO	YES	1-mode	ED/REL
U3	Gas network	NO	YES	1-mode	ED/REL

MATRIX CODE (A)	NETWORK (B)	DIRECTEDNESS (C)	WEIGHTS (VALUED) (D)	1- OR 2-MODE (E)	METRICS (F)
FE	Food exchange				
FE1	Food category 1	YES	YES	1-mode	Money
FE2	Food category 2 (fruit & vegetables?)	YES	YES	1-mode	Money
FE3	Food category 3	YES	YES	1-mode	Money
FE4	Food category 4	YES	YES	1-mode	Money
FE5	Food category 5	YES	YES	1-mode	Money
AI	Agricultural Inputs				
AI1	Agricultural inputs category 1	YES	YES	1-mode	Money
AI2	Agricultural inputs category 2	YES	YES	1-mode	Money
AI3	Agricultural inputs category 3	YES	YES	1-mode	Money
AI4	Agricultural inputs category 4	YES	YES	1-mode	Money
AI5	Agricultural inputs category 5	YES	YES	1-mode	Money
AI6	Agricultural inputs category 5	YES	YES	1-mode	Money
IE	Information exchange (for food system)				
IE1	Information exchange (for food system); face to face	YES	YES	1-mode	Information quant. FREQ
IE2	Information exchange (for food system) by telephone	YES	YES	1-mode	Information quant. FREQ
IE3	Information exchange (for food system) through other means	YES	YES	1-mode	Information quant. FREQ
AE	Advice Exchange				
AE1	Advice exchange (for food system) face to face	YES	YES	1-mode	Advice quant. FREQ
AE2	Advice exchange (for food system) by telephone	YES	YES	1-mode	Advice quant. FREQ
AE3	Advice exchange (for food system) through other means	YES	YES	1-mode	Advice quant. FREQ

MATRIX CODE (A)	NETWORK (B)	DIRECTEDNESS (C)	WEIGHTS (VALUED) (D)	1- OR 2-MODE (E)	METRICS (F)
PM	**People's mobility**				
PM1	People's mobility for job	YES	YES	1-mode	Time, cost, FREQ
PM2	People's mobility for health	YES	YES	1-mode	Time, cost, FREQ
PM3	People's mobility for education	YES	YES	1-mode	Time, cost, FREQ
PM4	People's mobility for public administration services	YES	YES	1-mode	Time, cost, FREQ
PM5	People's mobility for financial services	YES	YES	1-mode	Time, cost, FREQ
PM6	People's mobility for water sources	YES	YES	1-mode	Time, cost, FREQ
PM7	People's mobility for other aims (e.g., fuel for food prearation)	YES	YES	1-mode	Time, cost, FREQ
FF	**Financial flows**				
FF1	Remittances	YES	YES	1-mode	Money
FF2	Neighbours	YES	YES	1-mode	Money
AM	**Affiliation matrices**				
SP	Service providers *affiliation* network	NO	NO	2-mode	Money
WS	Water sources *affiliation* network	NO	NO	2-mode	Water Lt.

Note:
ED = Euclidean Distance
REL = index of reliability (e.g., road is always accessible or not accessible during rains / flooding etc.)
FREQ = frequency of exchange

Step 3: **SNA analysis**

As explained in the previous sections, SNA analysis for FSNS will take place at three levels (Figure 3) of aggregation: node level (micro), sub-structure of the network (meso), and whole network patterns (macro). Correlation analysis between the networks' features (topological attributes or network traits) at each single level and territorial and actors' attributes will then be conducted to understand how the structural features of networks correlate to food and nutrition security.

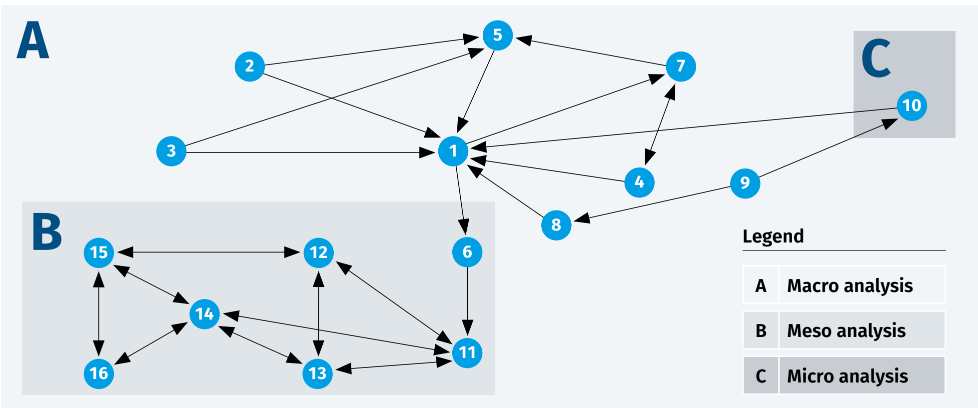
Table 3 provides a summary of the generally applied SNA measures and some general rules.

TABLE 3 **Main SNA measures**

Analytical level	SNA measures
Node (Micro) level	Centrality: degree, betweeness, closeness
Sub-Network (Meso) level	Clusters, cliques, clans, k-cores, k-plexes, etc.
Whole Network (Macro) level	Density, size, centralization, assortativity, degree of heterogeneity, degree of hierarchy, degree of actor's entropy, existence of small world structures, blockmodelling etc.
Network system	Aggregation of the networks in a network system providing a comprehensive mapping of FSNS. Main measures as for the macro-level analysis are used.

The node level (micro-level): one of the main objectives of SNA is to assess node (actor, vertex, ego) centrality. Finding out which is the most central node in FSNS analysis is important as it could constitute the channel through which for example information on food prices or agricultural prices or good agricultural practices could be disseminated faster in the relevant network (Borgatti, 2005). In principle, actors who have more ties may have multiple alternative ways and resources to reach goals and thus be relatively advantaged. Three main measures of centrality can be useful to analyze FSNS: the first, degree centrality, refers to the number of connections that one actor holds with his neighbors; the others refer to the number of connections with all other actors, regardless if adjacent or far. The micro level focuses on the relational and socio-economic characteristics of the actors and nodes within the network. Network actors can be defined as economic agents directly involved in the FSNS such as households, food dealers, farmers, food processors, farmers' associations, trade unions, public administration, NGOs, service providers to FSNS, hospitals, schools; while nodes can be defined to include also other territorial units such as police offices, roads, railway, airways, waterways and water network, and electricity network. The main analytical and policy related goal is to: understand the position of single actors within the FSNS; assess actors' role as brokers of information and resources; and investigate what socio-economic factors characterize the actors occupying central positions within the system as opposed to those sitting at the periphery or even excluded from participating into the system (Burt, 2009). For this purpose, centrality indexes can be computed and compared across each actor within the network.

FIGURE 3: **Multi-level SNA analysis of Food-sheds**



Meso-level measures: allow researchers to understand the structure and components of the network and to identify groups, clusters, and locations that may constitute bottlenecks to or opportunities for inclusive and efficient food systems. For example, it can inform on the monopolistic situations of some actors (e.g., input suppliers, producers, processors, retailers, etc.), exclusion of communities (e.g., religious groups, ethnic groups, etc.). The number, size, and connections among the sub-groupings in a network can tell us a lot about the likely behaviour of the network as a whole. How fast will things move across the actors in the network? Will conflicts most likely involve multiple groups, or two factions. To what extent do the sub-groups and social structures overlap one another? The idea that some regions of a graph may be less connected to the whole than others may lead to insights into lines of division (Zhong, *et al.* 2014). The numbers and sizes of sub-structures may be useful for predicting both the opportunities and constraints facing groups and actors, as well as predicting the evolution of the graph itself (De Nooy, *et al.*, 2011, pp 71-949). Members of the sub-structures tend to share similar attributes and higher cohesion.

This level of analysis can be used, for instance, to identify the presence of hidden communities, or those communities within which connections are dense, but between which connections are sparser. In other words, they identify more cohesive groups of actors. As opposed to hidden communities, explicit communities are those groups that share same attributes such as, their belonging to a same ethnic group or their adopting the same agricultural practices or accessing a same water source. The role and importance of hidden and explicit communities, can be assessed by calculating their: i) group centrality; ii) group density; and iii) group size. This level of analysis will also help identify the smallest group, the presence of which is key to ensure the network cohesion (also called integrators/diffusors) and/or those groups, the absence of which would disconnect the network, also called disconnectors. Furthermore, these measures can be used to understand how local relational patterns influence the overall configuration of the network. This has particular interest for policy analysis as it can simulate the impact of policy incentives targeted to some components of the network on the whole network configuration.

The macro-level differenciates food sheds on the basis of their overall configurations. The overall configuration of the network defines the inherent form of coordination in the food system. For instance, to be part of a cohesive network can result to be a trap due to the limited inflow of new information (Burt, 1992). On the contrary, the small world network characterized by a number of cohesive sub-groups linked one another by random ties is generally considered to be more conductive to innovation. For example, a group of farmers belonging to the same cohesive local social group share the same knowledge and opportunities, whereas farmers with connections to other groups of farmers are in a better position to have access to new knowledge and a wider range of opportunities.

Pre-specified and exploratory blockmodelling analysis can be used to assess and compare the overall configuration of the network (core-periphery, small-worlds, hierarchies, cycles, etc) and to identify key roles and positions within each system (Doreian *et al.* 2005; Ferligoy, 2011). This type of analysis was used to examine institutional variety, embeddedness and path dependence (Prota, 2016); structural exclusion from food systems in post-socialist rice economy of Vietnam (Prota and Beresford, 2012); institutional evolution and structural changes in technology district in Italy (Prota *et al.* 2017). Finally, a multilevel perspective can be adopted in the analysis where at least two levels of analysis are simultaneously accounted for (Wang *et al.* 2013, Lazega *et al.* 2015; Wang *et al.* 2016).

A summary of key FSNS policy related issues that can be assessed with the application of SNA is provided in Table 4.

TABLE 4: **Selected policy-related questions**

1	What is the geographic extension of FSNS? Is it local, national, international?
2	Are there sub-food systems or components of food systems that require particular attention by policy makers (i.e., street vendors based food systems, slums food systems, indigenous food systems, etc.)?
3	How does FSNS contribute to the local socio-economic dynamics in terms of, for example, employment generation, formal and informal sector, etc.?
4	Who are the actors that may require policy attention (e.g., households, farmers, peripheral actors, etc.)?
5	Who controls the flows of information and resources within a FSNS?
6	Who are the actors who have weak access to resources (transport, food, information, etc.)?
7	What is the degree of dependence of food systems from imported food?
8	Which are the groups that depend more on imported than domestically produced food?
9	What structural advantages do FSNS actors enjoy with respect to their market competitors and partners?
10	Which advantages do actors derive from their membership in associations and organizations?
11	What is the risk of remaining “locked in” closed local communities?
12	What is the role of local institutions in favoring dialogue, knowledge diffusion, and global bridging and dialogue between conflicting interest groups?
13	How are local communities structured and stratified?
14	Which actors are better positioned to stimulate innovative solutions to FSNS issues?

4 Conclusions

The underpinning assumption of the proposed application of Social network analysis (SNA) to Food Security and Nutrition Systems (FSNS) is that the performance of a food system in terms of inclusiveness and healthy diets depends on the collective behaviour of individuals. SNA reveals some fundamental insights about the influence that individual actors' behaviour (e.g., processors) have on the patterns and properties of the networks (e.g., food systems networks) and vice versa about the influence of networks structures on individual behaviour. By investigating into the multiple relationship patterns between socio-economic actors and the physical space within which actors operate, it also helps to understand the circumstances that affect actors' behaviours. Moreover, compared to other analytical tools SNA has the capacity to:

- capture the complexity of emerging challenges through the mapping and analysis of the the interplay between actors and the economic, social, environmental and natural resources related FSNS issues, as well as the feedback loops that are rarely taken into account in standard tools. It allows researchers to zoom in on individual behaviours (micro-level) within a system, on the sub-systems (meso-level) and the whole network properties (macro-level). In other words it could contribute to analyse systems of organized complexity and systems of disorganized complexity (Weaver 1948);

- recognize the bounded rationality of the decisions made by individuals, which according to (Simon 1957) are faced with three main constraints, namely cognitive constraint, outcome constraint and constraint on behavioural patterns. Moreover, individuals in a society also base their decisions on the behaviour of others (i.e., the social learning behavioural aspect of decision making). Without going as far as the famous quote by McNamara, former US Secretary of State under president John Fitzgerald Kennedy and president of the World Bank, that "rationality will not save us", it is widely accepted by most renown economists such as K. Arrow and A. Sen that perfect rationality is widely used because of its simplicity and usability but this assumption does not reflect the reality;
- combine qualitative and quantitative analysis at various levels of complexity;
- offer the possibility to involve actors in the development of the networks, to visualize and geo-reference the maps, analyse parts of the FSNS (e.g., only to the service provision networks or information dissemination networks) or the whole FSNS, and finally to understand, monitor and improve FSNS governance.

In brief, the purpose of this paper and of SNA is to provide practitioners with tools that will allow them to complement standard economic analysis of FSNS with a stronger social and institutional analysis on the increasingly recognized assumption "that there are many economic interactions where the social context is not a second-order consideration, but is actually a primary driver of behaviours and outcomes..." (Matthew, 2007).

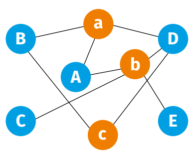
Annex

Glossary of key technical terms and metrics used in SNA methodology*

Affiliation network

Affiliation networks explore relationships that arise from common involvement in activities or other social events (Moore, *et al.*, 2003). To that end, affiliation network analysis simultaneously concentrates on the interacting entities (individuals, groups, etc.) and the events in which those actors are involved (Wasserman and Faust, 1994: 291-307). In affiliation networks both the actors and the events are represented as nodes; the edges connect the actors to the social events in which they partake. Affiliation networks can therefore be viewed from the perspective of the actors (since co-participation in events links actors together) or the perspective of the events (since participation of the same actors in multiple events links the events together; Faust, 2005). For example, although people (A, B, C, D, E) may not have direct ties to each other, as in the graph below, they may attend similar events (a, b, c) or activities in a community and in doing so this sets up opportunities for the formation of "weak ties". For example, A, D and E are not directly linked but they both participate in the same event b.

Nodes (2 sets)	a	b	c
A	1	1	0
B	1	0	1
C	0	1	0
D	1	1	1
E	0	1	0



Assortativity

A network topology where the hubs tend to link to each other and avoid linking to small-degree nodes. At the same time the small-degree nodes tend to connect to other small-degree nodes. Networks displaying such trends are assortative. The assortativity coefficient is a measure of the amount of mixing between and across subgroups of individuals with certain attributes (sex, age, node degree) as compared to that expected by chance. Flack *et al.* (2006) used the assortativity coefficient to assess whether changes in affiliative behaviours occurred when key individuals were temporarily removed from a pigtail macaque group and found that more assortative mixing occurred when key individuals were absent.

* The glossary is drawn and adapted from:

1. Carolan, B.V. 2014. Key Terms, Social Network Analysis and Education: Theory, Methods & Applications [online]. http://www.sagepub.com/carolan/study/materials/KeyTerms.pdf.
2. Datavu. 2013. Introduction to Network Analysis terminology [online] http://datavu.blogspot.com/2013/10/sna-social-network-analysis-basic.html.
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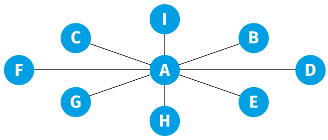
4. Ghali, N., Panda, M., Hassanien A.E., Abraham A., Snasel V. 2012. Social Networks Analysis: Tools, Measures and Visualization. In: Abraham A. (eds) Computational Social Networks. Springer, London.
5. Hawe, P., Webster, C., Shiell, A. 2004. A glossary of terms for navigating the field of social network analysis. Journal of Epidemiology & Community Health, 58, pp. 971-975.
6. De Nooy, W., Mrvar, A., & Batagelj, V. 2011; Makagon M.M., B. McCowan, and J. A. Mench (2013) How can social network analysis contribute to social behavior research in applied ethology? Published online (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3865988/).
7. Scott, J. 2017. Social Network Analysis. Fourth edition. University of Exeter, UK.
8. Wasserman, S., & Faust, K. 1994. *Social network analysis: Methods and applications* (Vol. 8). Cambridge University Press.
9. Zweig, K. & Iyengar, S. 2010. An Introductory Course on Network Analysis [online] https://sites.google.com/site/networkanalysisacourse/schedule/an-introduction-to-centrality-measures.

Betweenness centrality (Bc)

Betweenness centrality is the number of times an actor connects pairs of other actors, who otherwise would not be able to reach one another. It is a measure of the potential for control as an actor who is high in "betweenness" is able to act as a gatekeeper controlling the flow of resources between the alters that he or she connects. In the star graph below A has the highest betweeness as all the other actors in the network must go through actor A to reach all the others (Ronald S. Burt, 2009).

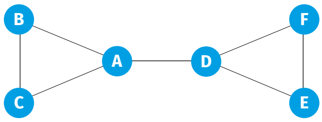


Blocks modelling

A blockmodel is a partition of a network into positions and roles. A position is a social space populated by actors sharing similar behaviours. For example, a position in the food system can be occupied by all the farmers that directly sell to some urban consumers. This position can be labeled "producers-traders" as it cluster all producers that also directly trade food. A role, also known as block, is defined as the set of relations linking one position to another. In the example above, a role in the food system can be "0 mile trading" as this role links the position of "direct sellers" with that of "urban consumers". By partitioning the whole network into roles and positions a blockmodel provides a simplified and comprehensive image of the food system as a integrated collection of diverse sub-food systems (Ferligoj, *et al.* 2011; Doreian *et al.* 2005).

Bridge

Bridge is a tie between two nodes, removal of which would break up a network into disconnected parts: A and D in the figure below are cut-points and the tie between and D is a bridge. Cut-points may act as brokers among otherwise disconnected groups. Cut-points and bridges are network's weak spots vulnerable to disruptions in the flow of information, resources, and influence.



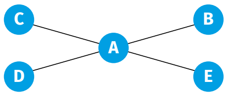
Centrality

It is a measure referred to single nodes, and expresses the number of connections with its neighbors (degree or direct centrality) or with all nodes (indirect centrality).

Centralization

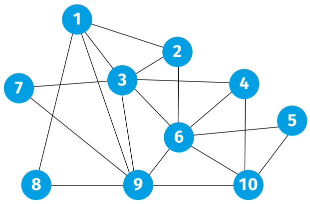
Centralization measures how equal are the nodes or how much variation is there in the centrality scores among the nodes. It expresses the variability in the degrees of actors as a percentage of that in a star network of the same size, which is the most centralized or unequal (high variance). Indeed in the star network, actor A has more opportunities and alternatives than other actors. If actor D decides to not exchange with A, A has still a number of actors to exchange with; however, if D decides to not exchange with A, then D will not be able to exchange at all. In the graph below, the star graph shows that actor A is linked to all other actors and has therefore a score of 4. All the other actors are linked only to actor A: therefore they all score 1.

The graph also shows that A has the highest node centrality. This is measured by calculating the number of times the other nodes have to go through A to be linked to the each one of the other nodes. In the star graph below this will happen 6 times: BtoE; BtoD; BtoC; CtoE; CtoD; DtoE. Thus the node A centrality is 6 as opposed to 0 for all the other nodes. The centrality index (CI) of the graph is calculated as the sum of the differences between the highest centrality node (in this case A=6) and the centrality of the other nodes (in this case 0) divided by the sum of the differences between the normalized differences between the max centrality node (A=6) and the centrality of the other nodes (0). The centralization index will be 1. It is worth noting that for the star graph CI is always equal to 1.
$\Sigma(C^*\text{-}Ci)/\text{Max}\ \Sigma(C^*\text{-}Ci) = 24/24 = 1$



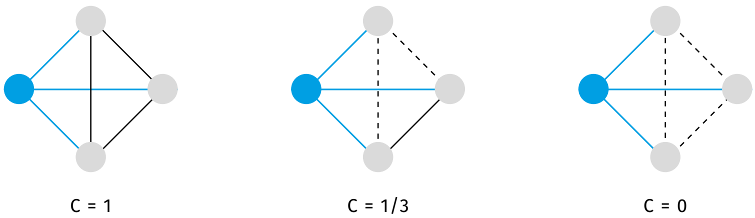
Clique

A clique is a subgroup of actors who are all directly connected to one another and no additional network member exists who is also connected to all members of the subgroup. That is, it is defined by the attribute of “completeness”. Cliques in directed networks can be strong (each couple of nodes has to be connected by a reciprocal tie) or weak (ignoring reciprocity). In the graph below 8 cliques can be identified: 1,2,3; 1,8,9; 3,7,9; 3,4,6; 2,3,6; 3,6,9; 4,6,10; 6,9,10.



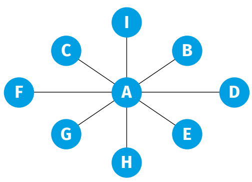
Clustering

A measure of a network of actors' tendency to "group together" into pockets of dense connectivity. In the first graph on the left hand side below, the blue node has a clustering coefficient of one, because all possible connections among its neighboring nodes have been realized. In the second image, only one of the possible connections has been realized. So the blue node has a clustering coefficient of 1/3. In the third image, none of the neighboring nodes are connected, so the blue node has a clustering coefficient of 0.



Closeness centrality

Closeness centrality is based on the notion of distance. If an actor is close to all others in the network, a distance of no more than one, then s/he is not dependent on any other to reach everyone in the network. Closeness measures independence or efficiency. With disconnected networks, closeness centrality must be calculated for each component. For the largest component in figure 1, actors 19 and 3 again are the most central. In the star graph below, actor A is the most independent actor with a total number of eight links as opposed to one link for all the other actors.

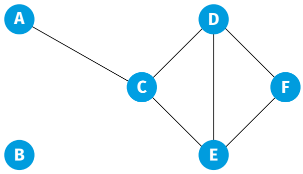


Communities

Communities are can be defined as denser areas of the network. Actors have more ties within their community than to any other actors in the network. There are many different community detection algorithms available for social networks. These algorithms are particularly useful to simplify large networks into simpler graphs (Fortunato, 2010). Girvan and Newman (2002) developed an algorithm to quantify the number of communities in a network using the notion of edge betweenness, which is the number of shortest paths between nodes that make use of an edge or connection.

Component

A component is a portion of the network in which all actors are connected, directly or indirectly, by at least one tie. By definition, each isolate is a separate component. There are two components in the figure below, one large component and one isolate.



Configurations

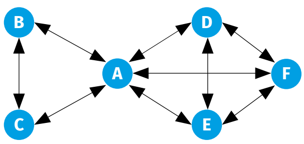
Usually they refer to some specific topology, but in ERGM they refer to the elementary structures on which a specific model is built. In the biological literature are usually called “motifs”.

Core-periphery

A network property characterized by the existence of a (supposedly small) set of highly connected nodes and a large set of lowly connected nodes. A core is a densely connected cluster where members are all related to each other; while the periphery is a sparse region of the network whose nodes don’t have ties and another but they are instead all related with the core (Fagiolo *et al.* 2010; Rombach, 2017).

Cut-point

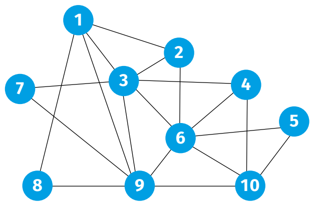
Cut-point is a node, removal of which would break up a network into disconnected parts: A is the cut-point of the network



Degree centrality

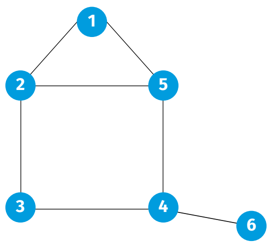
Measures the number of connections with adjacent nodes. If the network is directed, then a distinction is made between indegree (In-Dc) and outdegree (Out-Dc): indegree is counts the number of ties directed to the node and outdegree is the number of ties that the node directs to others. Indegree means that many actors seek to direct ties to one actor. It may be regarded as a measure of importance of the actors receiving many ties. Actors who have high outdegree centrality may be relatively able to exchange with others, or disperse information quickly to many others.

So actors with high outdegree centrality are often characterized as influential. Lots of ties coming in and lots of ties coming out of an actor would increase degree centrality. In the graph below, actor 3 has the highest degree centrality with six direct ties (1,2,4,6,7,9) and actor 1 is the next most central with four direct ties (2,3,8,9).



Degree distribution

A frequency count of the occurrence of each degree. In the undirected graph below the degree distribution is as follows.

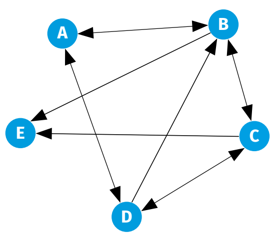


Nodes	Degree	Frequency of degree:	Average degree
1	2	1: 1/6	2L/N
2	3	2: 2/6	where L= edges
3	2	3: 3/6	and N= nodes:
4	3		
5	3		2*7/6 = 7/3
6	1		

Degree is interesting for several reasons. In a social network, the ones who have connections to many others might have more influence, more access to information, or more prestige than those who have fewer connections. The degree is the immediate risk of a node for catching whatever is flowing through the network (such as a virus, or some information).

Density

Absolute density counts the number of links connecting actors, while relative density normalize that value with the maximum number of possible ties. For directed (asymmetric) networks, the number of possible ties is n*(n-1), for undirected (symmetric) it is n*(n-1)/2 where n = number of actors.



Number of actual ties if undirected

	A	B	C	D	E	Total
A		1		1		2
B			1	1	1	3
C				1	1	2
D						0
E						0
						7

Number of actual ties if undirected

	A	B	C	D	E	Total
A		1		1		2
B	1		1		1	3
C		1		1	1	3
D	1	1	1			3
E						0
						11

Potential number of ties if undirected = n*(n-1)/2 = 10
potential number of ties if directed = n*(n-1) = 20
Density undirected = 7/10 = 70%
Density directed = 11/20 = 55%

Diameter

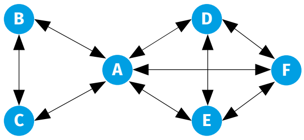
Diameter is the largest geodesic distance in the (connected) network

Direction of link

The links between nodes can be directed or undirected (see figure below). Directed edges define a one-way relationship and are usually represented with arrows indicating the direction of the relationship. Directed edges are also called *asymmetric*. Undirected edges are a two-way and perfectly symmetric relationships between nodes because the edges can be traversed in both directions. They are represented with lines with no arrows. For instance, the transportation network is undirected because the edge of every pair of nodes (e.g., links between cities), also called *dyads*, can be traversed in both directions (e.g., trains connect cities in both directions).

Distance

Distance between two actors in a network (or nodes in a graph) is calculated by summing the number of distinct ties (lines) that exist along the shortest route between them. So in the figure below actor B is a distance of 1 from actor A and C, and a distance of 2 from all other actors.



Diversity

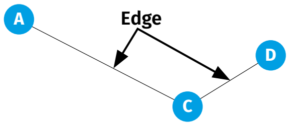
While efficiency is about getting a large number of (nonredundant) nodes, a node's diversity, conversely suggests a critical performance point of view where those nodes are diverse in nature, i.e., the history of each individual node within the network is important.

Dyad

Couple of nodes which can be connected by an edge or can be unconnected.

Edge, tie, arc, link

Synonyms to express a connection linking a couple of nodes. Edges can be directed or undirected, binary or unvalued, depending on the nature of the network. The use of a term respect to another depends on the approach to network study: "arc" is used in graph theory; purely statistical approaches prefer the terms "edge" and "tie"; "link" is frequently used in complexity-related perspectives.



Effectiveness

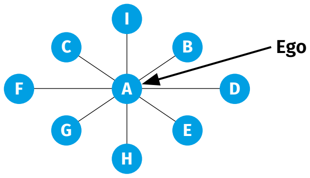
Effectiveness targets the cluster of nodes that can be reached through nonredundant contacts. In contrast, efficiency aims at the reduction of the time and energy spent on redundant contacts. Each cluster of contacts is an independent source of information. One cluster around this nonredundant node, no matter how numerous its members are, is only one source of information, because people connected to one another tend to know about the same things at about the same time. For example, a network is more effective when the information benefit provided by multiple clusters of contacts is broader, providing better assurance that the central node will be informed. Moreover, because nonredundant contacts are only connected through the central node, the central node is assured of being the first to see new opportunities created by needs in one group that could be served by skills in another group.

Efficiency

Number of nodes that can instantly access a large number of different nodes through a relatively small number of ties. These nodes are treated as nonredundant contacts. Efficiency is therefore measured by the number of nonredundant contacts and the average number of ties an ego has to traverse to reach any alter, this number is referred to as the average path length. The shorter the average path length relative to the size of the network and the lower the number of redundant contacts, the more efficient is the network.

Ego-centric networks

Ego-centric or personal networks are defined from a focal actor's perspective only. This refers to the ties directly connecting the focal actor (ego) to others (ego's alters) in the network, plus ego's views on the ties among his or her alters. An example would be if we asked a farmer to nominate the people s/he exchanges information with, and then asked that same farmer to indicate who in that network socializes with the others nominated. In the figure below, A is the ego and all the other actors are alters.



Eigenvector centrality

An important node is connected to important neighbors. This is a measure of influence of a given node in the whole network. The notion is how well-connected a given node is with other well connected nodes in the network.

Emergent properties

These are system's properties that cannot be predicted, and usually neither individuated, according to the properties and behaviours of system's elements taken in isolation. Emergent properties are typically generated by self-organizing systems, which in turn are characterized by recursive interactions. Unintended outcomes are those emergent properties of social systems that come from simple and individual behavioural rules that did not aim at, or were not designed to, reach those outcomes.

Exponential Random Graph Model (ERGM)

A statistical model that can be used to estimate the effects of covariates on the ties in a network while simultaneously estimating parameters that provide a precise and parsimonious description of the forms of dependence that can exist in relational data (Robins *et al.* 2009).

Fragmentation

Using the concept of cut point, fragmentation is defined as the proportion of mutually reachable nodes as each node is removed from the network (Borgatti, 2003). Fragmentation is an inverse measure of the amount of connectedness or connection redundancy in a network. McCowan *et al.* (2008) hypothesized that lower fragmentation (thus a higher degree of redundancy in dominance interactions among actors) should result in less ambiguity about dominance relationships.

Geodesic distance

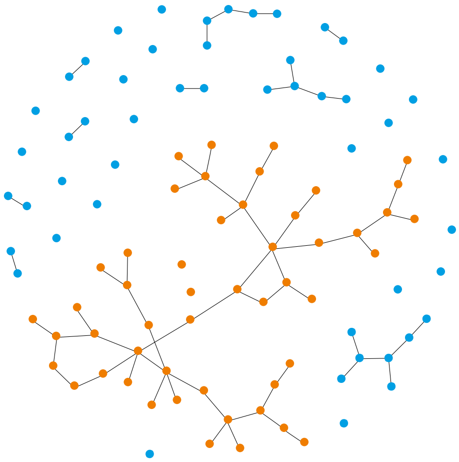
Geodesic distance is the number of relations in the shortest possible walk from one actor to another. A distance measure corresponding to the shortest path between a couple of nodes. It is calculated by counting the number of ties which define the path; if there is no path between the couple of nodes, the geodesic can be defined as infinite.

Geodesic path

The geodesic path or paths, as there can be more than one, is often the "optimal", "shortest" or most "efficient" connection between two actors (nodes).

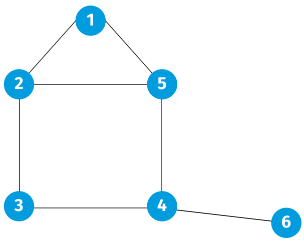
Giant component

A giant component is a connected component in a large network. In real undirected networks, we typically find that there is a large component (the giant component) that fills most of the network, usually more than half and not infrequently over 90%, while the rest of the network is divided into a large number of small components disconnected from the rest. Examples of networks for which giant components fill the entire network are Internet, transportation networks, power grids, etc. The situation is exemplified in the following figure.



Global clustering

The global clustering coefficient is defined as the number of closed triads (or triplets) over the total number of triads (both open and closed). A triangle consists of three closed triads, one centered on each of the nodes of the triad. The global clustering coefficient is the number of closed triplets (or 3 x triangle) over the total number of triplets (both open and closed): CC = 3 × number of triangles/number of triplets = number of closed triplets/number of triplets. Three configurations yield a triad: 1 is linked to 2 who is linked to 5; both 1 and 2 are linked to 5; or both 2 and 5 are linked to 1. The percentage of closed triads in a network is three times the total number of closed triads (to account for the three possible configurations of triads) divided by the total number of actual triads. A clustering coefficient varies from 0 to 1. Zero represents no clustering and 1 represents full clustering. A value of 0.65 means that 65% of the triads are closed. In the graph below, average clustering and global clustering coefficient will be:



Node	Clustering coefficient	Clustering coefficient C	Frequency	Average clustering	Global clustering coefficient
1	1	0	2/5	(2/5+2/5+	**3/11**
2	1/3	1/3	2/5	2/5)/3 =	
3	0	1	1/5	**1/3**	
4	0				
5	1/3				
6	NA				

Clustering can be used as a probe for the existence of so-called structural holes in a network, which are missing links between neighbors of a person (Burt, 1992). Structural holes can be bad when we are interested in efficient spread of goods or information or other transactions around a network because they reduce the number of alternative routes exchanges can take through the network. Structural holes can be good thing for the central vertex whose friends lack connections because they give it power over information flow between those friends.

Graphs

Graphs are visual representations of network matrices, displaying actors as nodes and the relational ties connecting actors as lines (ties, edges). They can be single-mode graph: type of graph in which all nodes belong to the same category. For example, in a graph of Facebook friends, each node is a person. They can also be multimode graphs: a type of graph in which all nodes are not of same type. For example, a graph that includes both “buyers” and “sellers” is a multimode (or two-mode, or bimodal) graph.

Hierarchy

A network characterized by a certain degree of (direct and indirect) asymmetry among its dyads or by a high degree of direct centrality among its nodes. The archetype of hierarchy is a perfect out-tree whose links represent decisions. An out-tree graph is a directed graph in which all points are connected, and all but one node (the “boss”) has an in-degree of one. This means that all actors in the graph (except the ultimate “boss”) have a single superior node (Krackchardt, 1994).

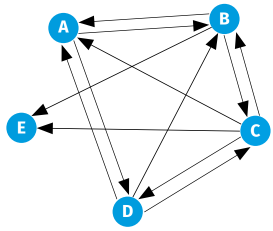
The simplest "hierarchy" is a star graph where only one nodes has in-degrees from all other actors and all other actors have only one in-degree. Three types of hierarchy are proposed (https://arxiv.org/pdf/1202.0191.pdf): the order, the nested and the flow hierarchies.

Isolates

See Reachability

Matrix

Data from a network survey are typically entered into a database as a square actor by actor similarity or distance matrix. Presence of a tie is indicated with a "1" and no tie is indicated by a "0". Table 1 is a matrix of network relationships among 5 actors. It shows data generated from the question "From this list, can you identify which actor you are selling food to?" Alice sells to Bob and David (row 1)



Matrix Food Exchange (a)

Nodes	A	B	C	D	E
Alice	0	1	0	1	0
Bob	1	0	1	0	1
Clare	1	1	0	1	1
David	1	1	1	0	0
Eddie	0	0	0	0	0

Multiplex

Network defined by one set of nodes and two or more sets of links. Links of different sets represent qualitatively different relations connecting the nodes. Each type of link generates a potentially different topology.

Neighbor

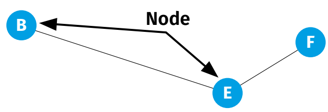
A node which is connected to the focal node by a link. The set of a node's neighbors is called "neighborhood".

Network

A set of points connected through a set of links.

Node

Entities in graph (also called vectors, actors, vertex). For example, if we consider Facebook friends as a graph, then every friend is a node.

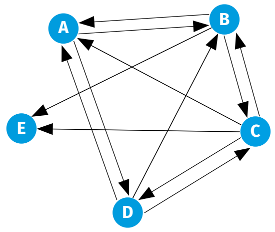


Node's attribute

Variable defining a non-relational (individual) attribute of a node. It can be used: i) to select a sub-network; ii) to interpret outputs of the application of relational techniques; iii) to investigate the influence of individual factors on relational factors and vice versa.

One-mode networks

One mode networks involve relations among a single set of similar actors, such as food exchange among farmers (Alice, Bob, Clare, David, Eddie) within a village.



Matrix Food Exchange (a)

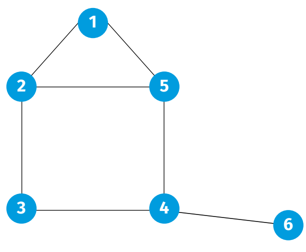
Nodes	A	B	C	D	E
Alice	0	1	0	1	0
Bob	1	0	1	0	1
Clare	1	1	0	1	1
David	1	1	1	0	0
Eddie	0	0	0	0	0

Path

A sequence of edges which connects a sequence of nodes. In general, nodes can appear only once in the sequence (distinguishing paths from "walks"). Paths can be undirected or directed – depending on the nature of the network – and, in the case of directed networks, strong (considering the direction of the edges in the sequence) or weak (not considering the direction of the edges).

Path length (average)

Average number of steps along the shortest paths for all possible pairs of network nodes. It is a measure of the efficiency of information or mass transport on a network. In the undirected graph below average path length (distance) is calculated in two steps: path distribution, frequency count of the occurrence of each path distance.



Network of shortest paths

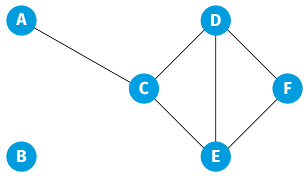
	1	2	3	4	5	6
1	0	1	2	2	1	3
2	1	0	1	2	1	3
3	2	1	0	1	2	2
4	2	2	1	0	1	1
5	1	1	2	1	0	2
6	3	3	2	1	2	0

Distance: frequency	Average
1: 14/30 2: 12/30 3: 4/30 *30 = max N. of shortest paths*	(14*1)+(12*2)+(4*3)/30 = 5/3

Path is interesting for several reasons. Path captures the indirect interactions in a network, and individual nodes benefit (or suffer) from indirect relationships because friends might provide access to favors from their friends and information might spread through the links of a network. Path is closely related to small-world phenomenon. Path is related to many centrality measures.

Reachability

Reachability measures whether actors within a network are related, either directly or indirectly, to all other actors. Actors who are not connected to any other actors are called isolates. With the exception of one isolate (actor B), all of the remaining actors in the figure below can reach one another.



Recursiveness

It is a fundamental property of complex dynamic networks: it means that interactions (or network flows) follow a cycle, which is repeated with (often nonlinear) feedback effects.

Robustness

Robustness of networks can be measured based on how it becomes fragmented when an increasing fraction of nodes is removed. It is measured as an estimate of the tendency of individuals in networks to form local groups or clusters of individuals with whom they share similar characteristics, i.e., clustering. For example, if individuals A, B, and C are all input providers and if A knows B and B knows C, then it is highly likely that B knows C using the so called chain rule. If the measure of the clustering of individuals is high for a given network, then the robustness of that network increases within a cluster/group.

Self-organizing systems

A self-organizing system is a system whose behaviour is largely (if not entirely) determined by its own structure (topology) and rules of behaviour. To be self-organizing, a system needs to be characterized by recursive interactions. Self-organizing systems produce unintended outcomes or emergent properties, which can be positive or negative.

Small-world network

Network topology whose most relevant characteristics are short average distances and high global clustering. That is, that on average even in a very large small-world network actors are separated by only limited (six according to Milgram 1967) degrees of separation or intermediaries or superconnectors (https://www.kellogg.northwestern.edu/faculty/uzzi/ftp/Uzzi_EuropeanManReview_2007.pdf).

To quantify a small world, two network measures can be used (Watts and Strogatz): average path length (L) and the clustering coefficient (CC). L measures the average number of intermediaries, that is, the degrees of separation, between any two actors in the network along their shortest path of intermediaries. The shorter the average path length, the closer people, resources, or ideas theoretically are to each other in the network. The CC measures how many of an actor's contacts are connected to each other. When many of an actor's contacts are connected to each other, the actor has a highly clustered or cliquish network.

Social networks

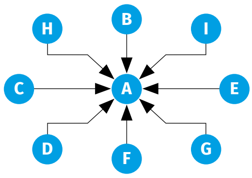
A finite set (or sets) of actors and the relations defined on them. It consists of three elements: (1) a set of actors; (2) each actor has a set of individual attributes; and (3) a set of ties that defines at least one relation among actors.

Socio-centric networks

Socio-centric or complete networks consist of the relational ties among members of a single, bounded community. An example would be relational ties among all of the farmers in a farmer association.

Star graph

Prototypical network structure consisting of a subset of nodes of a graph. The star is defined by a central node – which is connected to all the other nodes – and the remaining N-1 nodes, which are only connected to the central node.



Sub-network

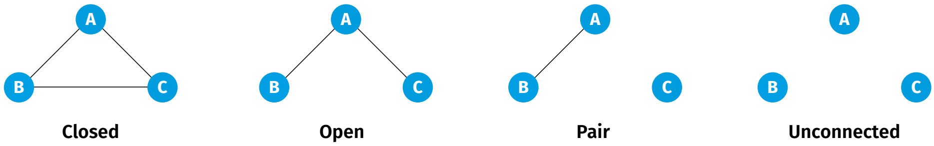
A sub-sample of a network. It is composed by a set of nodes which are selected according to theoretical and/or pragmatic criteria and the set of links connecting them.

Topological distance

This type of distance does not coincide necessarily with geographical distance. For example, the two geographically distant actors may have a direct food exchange, direct in the sense of without any intermediate actor. Conversely, two geographically close actors might have many intermediaries.

Topology

A specific structure of a network: it specifies who is connected with whom, that is links distribution. A triad is simply three nodes interlinked in some way. All possible undirected triads are shown in the graph below which shows that only the first two have all of their nodes interconnected, and thus present a significant interest. There are 16 possible directed triads.



Two-mode network

See Affiliation network

Unvalued (or binary or dichotomous) network

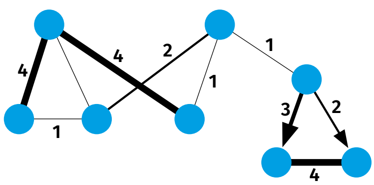
Network whose links are expressed in binary form (1/0) representing the presence/absence of the relation.

Valued network or weighted network

Network whose links are expressed by discrete or continuous quantities representing the intensity of the relations.

Weight

In the real world, not all links in a network have the same strength, intensity, or capacity. In this case we talk about a valued (weighted) network. Weights are measured using any relevant unit (e.g., monetary value of the exchanges of food, traffic of flows along transportation connections, quantity of CO_2 exchange between agricultural activities and the atmosphere, etc.). In the figure below, numbers and thickness of the lines express the intensity of the links/ties.



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A methodological approach

Evidence shows that food insecurity, poverty and geographic disparities in developing countries are strongly correlated. The proposed methodology aims to capture the spatial dimension of food insecurity, shed light on how food systems work and understand what determines food security and nutrition levels in a given space and time. It proposes an analytical framework to conduct a comprehensive, participatory and integrated assessment of Food Security and Nutrition Systems (FSNS) patterns focusing on three broad categories of exchanges determining food landscapes (i.e., mobility of people, goods, and services) and on the interplay between the actors involved in these exchanges, including their (in)formal institutions and networks.

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