From GMOs to nanotechnologies: a survey to researchers and experts on European agricultural legislation

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Preface

This master thesis is the fruit of the work at Wageningen University and Research in the Agricultural Economics and Rural Policy group and in the Public Administration and Policy group over the past six months. This study is meant to explore and understand what researchers and experts' perceptions are towards the European legislation to develop and commercialize nanotechnologies in agriculture. At the European level, most of research has been done to understand societal barriers to the introduction of new technologies in agriculture, but no study seems to directly assess how scientists and experts deal with the regulatory frameworks for nanotechnologies and how these rules influence the innovation and commercialization processes. Hence, the aim of this study is to contribute to broaden and deepen the current state of the art knowledge surrounding the introduction of new technologies in agriculture, and to provide new insights from which European policy makers can draw up comprehensive legislation.

I am grateful to all those people that supported me throughout these months. In particular, I would like to deeply thank Prof. Dr. Justus H.H. Wesseler and Dr. Tamara A.P. Metze-Borghouts for the opportunity to work with them and for the great and stimulating collaboration we had during these last months. I thank Prof. Dr. Aldrik H. Velders, Prof. Dr. Ir. Karin C.G.P.H Schroen and Dr. Ir. Frans W.H. Kampers for the enriching discussions that contributed to a broader understanding and knowledge on nanotechnologies in agriculture. Moreover, I also thank Claudia Parisi from the Joint Research Centre and Stuart J. Smyth from the University of Saskatchewan (Canada) for sharing with me contacts to undertake this research. Finally, I would like to thank my family. First of all Francesco for being supportive, for his esteem and for the inspiring conversations we had. My parents, for their lovely support and admiration, and for giving me the opportunity to study at Wageningen UR. Last but not least, I would like to thank my brother and his family for their esteem, love and cheering spirit.

Abstract

The introduction of nanotechnologies in agriculture is controversial. On the one hand, their application as smart delivery systems is seen as a promising tool to reach European sustainability goals and to optimize agricultural production. On the other hand, (eco-)toxicological negative effects are possible to affect both environment and human health. Furthermore, there is the concern of GMOs recurrence. Thus, European legislation is moving towards ensuring environmental and health safety measures, and promoting competitiveness and innovation. This study analyses what researchers and experts' perceptions are towards the European legislation to develop and commercialize nanotechnologies in agriculture. Results are based on an online questionnaire sent between November and December 2017. Results show first, a high acceptance of the definition of nanotechnologies recommended by the European Commission; second, researchers and experts perceive the risk assessment and risk management as strict and as not encouraging the development and commercialization of nanotechnologies in agriculture; third, researchers and experts' judgments towards the recommendations to conduct a responsible research and innovation process are extremely polarized, having some of the respondents supporting these guidelines and others disapproving them. A factor analysis is performed to capture respondents' perception factors. Then, a cluster analysis is conducted based on factor scores to group researchers' and experts with similar perceptions. The results display that respondents perceptions can be divided in five clusters: Confidence in the development and commercialization of agro-nanotechnologies, GMOs and NGOs barriers, Legislation skepticism, Definition acceptance and RRI dualism. Providing researchers and experts' points of view on European legislation contribute to the inclusion of new understandings surrounding the development and introduction of new technologies in agriculture. This provide essential and new information for policy makers for future legislation tailored to nanotechnologies.

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Chapter 1 – Introduction

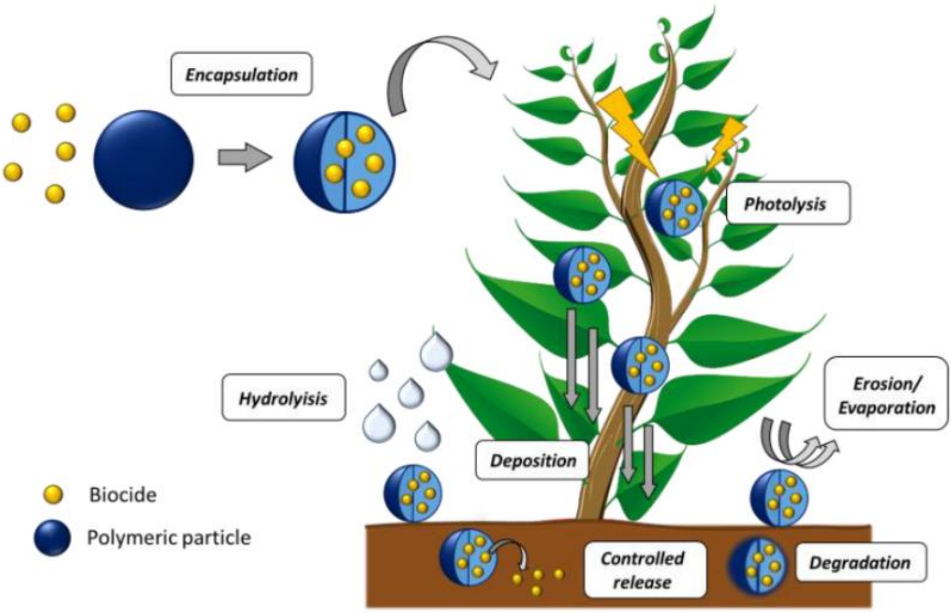
1.1 General Introduction

As defined by the European Commission (2011) a nanomaterial is "a *natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm - 100 nm."*. Originally introduced in 1980s, European Framework Programmes (FPs) are *ad hoc* schemes created by the European Union to support research and technological development (European Parliament, 2017). Since FP6, nanotechnologies are one of the main thematic areas of the programme. Together with advanced materials, biotechnology and sustainable development, nanotechnologies are recognized as one of the Key Enabling Technologies (KETs) in the European Union Horizon 2020 FP. The European Commission estimates to invest 533.80 million euros for KETs development in 2018 (European Commission, 2017) with the purpose of enhancing European competitiveness at a global scale, leading to economic growth and job creation (European Commission, 2014). Moreover, in the Global Nanotechnology Market Outlook 2024, it is forecasted that the global market for nanotechnology will increase by 17% in the period 2017-2024, reaching $75.8 billion by 2020 (PRNewswire, 2015).

Nanotechnologies are considered as an *"invisible industry"*, since nanomaterials are not sold directly but as raw materials (Justo-Hanani & Dayan, 2014). Due to their small size, nanomaterials have different physical, chemical, optical and mechanical properties compared to their bulk form (i.e. aggregate form). This is translated into materials with enhanced characteristics such as stiffness, permeability, crystallinity, thermal stability and conductivity, biodegradability and larger surface area (Nuruzzaman et al., 2016). This is why nanotechnology applications can be found in almost every industrial sector: chemicals, medicine, electronics, health care, biotechnology, energy and food (Bugusu et al., 2011; Parisi et al., 2015; Siegrist et al., 2011).

With the G*reen Revolution* in the second half of 20th century, the extensive use of pesticides and fertilizers, together with new mechanized technologies, almost doubled cereal production and substantially increased food security (Capocci, 2008). From that moment on, extensive research aimed at improving crop resistance and effectiveness of pesticides formulation has been carried out (de Oliveira et al., 2014), being insects, pests and diseases the major causes of yield losses (Khater, 2011). However, excessive application of pesticides led to negative environmental and health effect (e.g. water and soil pollution, soil degradation, destabilized soil and marine ecosystem, and carcinomic effect on humans) (Blair et al., 2015; de Oliveira et al., 2014; Nicolopoulou-Stamati et al., 2016). This, together with the expected population growth – up to 8.6 billion in 2030 and 9.8 billion in 2050 – and the subsequent increase in food demand between 50-100% (European Union, 2017; United Nations, 2017), highlights that optimization of agricultural production is undelayable. In this context, nanotechnology can be a promising tool in supporting a shift from conventional farming to precision farming (Frewer et al., 2011; Parisi et al., 2015). In fact, albeit the number of chemical substances in the nano form is uncertain (EUON, 2017b; Kah & Hofmann, 2014; Parisi et al., 2015), their implementation as agricultural inputs (e.g. pesticides and fertilizers) could make a significant contribution in the use of smart delivery systems (i.e. controlled and targeted release of active ingredients), in reaching a sustainable agriculture, reducing water and soil pollution and soil degradation, and fighting climate change (Chaudhry et al., 2011; Chhipa, 2017; Chowdhury et al., 2017; Khot et al., 2012; Omanovic-Miklicanin & Maksimovic, 2016; Siegrist et al., 2011) (see Figure 1).

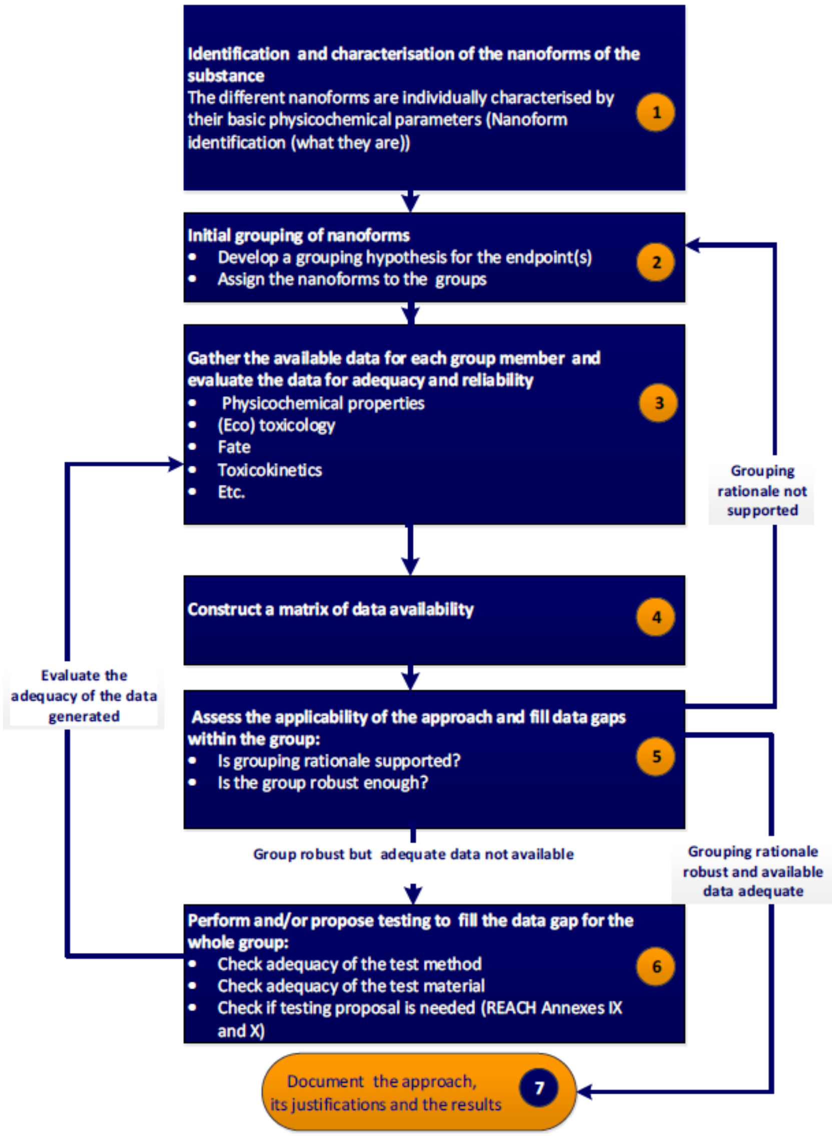
Figure 1 - Nano-encapsulated pesticide delivery (Álvarez-Paino et al., 2017).



However, due to nanomaterials unique molecular behaviour, their interaction with the environment and humans may have toxic effects (Seller et al., 2015), and this is why specific regulations for assessing their risks have been adopted (Magnuson & Bouwmeester, 2011). With regard to nanotechnologies applications as agricultural inputs, the ECHA (i.e. European Chemical Agency) is the institution that has the role of assessing and evaluating the risk of chemical substances. Thus, it implements REACH (Registration, Evaluation, Authorisation and restriction of Chemicals), CLP (Classification, Labelling and Packaging) and BPR (Biocidal Products) regulations. Under the REACH and the CLP regulations, the ECHA is responsible for assessing chemical safety of any substances, and for labelling any mixture. The BPR regulation specifies that biocidal products containing nanomaterials are not eligible for a simplified authorisation procedure. Hence, their risks must be assessed with a specific procedure that the ECHA reported in detail with precise guidelines for both public and private institutions (see Figure 2 in the next page).

Together with the regulations aforementioned, the RRI framework is another tool with which new technologies (here nanotechnologies) are dealt at the European level. Following the intense debate on GMOs, in 2011 Octavi Quintana, Director of the European Research Arena, introduced the concept of Responsible Research and Innovation (RRI) to avoid *"misunderstandings and difficulties"* between science and society (von Schomberg, 2013). The watchword for conducting a responsible research and innovation, as intended in the definition included within the Horizon 2020 Programme, is *"Science with and for society"*. This concept subsequently became a framework in which guidelines were proposed to connect society and scientific community, and to ensure correctness, honesty and transparency in the development of new technologies. Thus, it is meant to both minimize societal concerns and to maximize the likelihood of acceptancy of new technologies, especially in the agri-food sector.

Figure 2 - ECHA scheme for nanomaterials identification and characterisation (ECHA, 2017).



1.2 Problem definition

Although in the academia and in governmental institutions extensive research has been done to understand the key drivers for societal acceptance and resistance of both GMOs and nanotechnologies (Blancke et al., 2015; Couée, 2016; Eurobarometer, 2010; Kahan & Rejeski, 2009; Lucht, 2015; Valeria et al., 2016), just a handful has been done to investigate researchers and experts perceptions on the acceptance of several factors. For example, Chenel et al. (2015) examined researchers' acceptability of nanocarriers for drug delivery, and Gupta et al. (2015) analysed researchers' concerns over public acceptability of nanotechnologies. Moreover, Jones (2008) reported that researchers are unsettled with regard to societal perceptions. However, there seems to be no study on what researchers and experts' perceptions are with regard to both the regulatory framework they have to comply with and with the recommended RRI process at the European level. Furthermore, these actors' judgments on the role of NGOs and GMOs "inheritance" in jeopardizing the development and commercialization of agro-nanotechnologies are inspected. Thus, this study could be a starting point for further considerations in drawing up nanotechnology legislation.

1.2.1 Research objective

This study is aimed to investigate researchers and experts' perceptions towards European legislation (i.e. risk assessment and risk management regulatory framework, and responsible research and innovation framework) for the development and commercialization of nanotechnologies in agriculture.

1.2.2 Research questions

Main research question

What are researchers and experts' perception towards the European legislation for the development and commercialization of nanotechnologies in agriculture?

Sub-questions

i. *What are researchers and experts' opinions towards the Risk Assessment (RA) and Risk Management (RM) regulatory frameworks to develop and commercialize agro-nanotechnologies?*
ii. *Are researchers and experts in accordance with the European recommendations to conduct a Responsible Research and Innovation (RRI) process?*

Chapter 2 – Theoretical background

2.1 Why new agricultural technologies became highly regulated in EU: the case of GMOs.

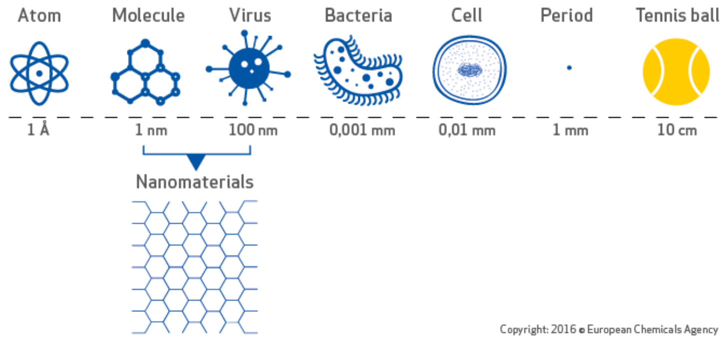
The watershed of biotechnological revolution was achieved by Herbert Boyer and Stanley N. Cohen in 1973 with the development of recombinant DNA technologies – rDNA – (i.e. genetic engineering of living organisms). As reported by Wesseler (2014), rDNA technologies brought to several breakthroughs (e.g. production of human insulin and vaccine against swine diarrhoea in heterologous systems under controlled conditions). In agriculture, the use of rDNA technologies led to the first genetically engineered (GE) crop to be commercialized – the *FLAVR SAVR tomato* developed by Calgene, Inc. in 1995 (Bruening & Lyons, 2000) – and to the first GE crop approved at European level – the MON810 *Bt Maize* (i.e. *bacillus turingensis*), developed by Monsanto in 1998. However, the development of genetically modified organisms (GMOs) was about to face strong barriers at the European level.

The European history of Genetic Modified Organisms (GMOs) is particularly troubled. Although the bovine spongiform encephalopathy (BSE) – also known as "mad cow" disease – was spreading in the early 1980s, the British Government first did not recognize the disease, and then delayed its intervention to protect its markets from public panic. However, the BSE disseminated throughout Europe, undermining the credibility of Governmental institutions (Smyth et al., 2014). This controversy led to a policy-making process in which transparency and openness became the core features. When the European Commission approved the first genetically modified crop in 1996-1997 – the MON810 *Bt Maize* –, mass media and NGOs activists started to criticize the use of GM crops, raising societal concerns. These were then translated into appropriate regulatory criteria to be applied to GMOs (Gottweis, 2005). In 2000, the Commission issued the communication on the precautionary principle (PP), which needs to be applied to the risk management whereby *"[…] if there is no scientific consensus on the issue, the policy or action in questions should not be pursued"* (EUR-Lex, 2000; European Commission, 2000). The European governmental institutions were shifting towards a more apprehensive and comprehensive decision-making process, which was translated into a stricter regulatory framework (Blancke et al., 2015). Despite in 2001 the European Commission declared that the PP shall not be used on arbitrary or discriminatory basis but on scientific evidence (European Commission, 2001), it was invoked by Member States with the intent of blocking GMOs development to avoid possible coming risks (Tagliabue, 2015). Member States started to ask for more precautionary criteria, up to a *de facto* moratorium on new GM crops from 1999 to 2004. Even countries that at the beginning were in favour of GM crops (e.g. France, Austria, UK), now blocked their approval (Les, 2014). The introduction of the PP lays the foundation to establish the EFSA (i.e. European Food Safety Authority) and the General Food Law in 2002 with the Regulation (EC) N 178/2002. Along with the development of regulatory criteria for the assessment and management of GMOs, the Common Agricultural Policy (CAP) and its reforms were placing greater emphasis on environmental provisions and in optimizing agricultural production. Therefore, agricultural biotechnologies became highly regulated in the European Union (Baldwin & Wyplosz, 2015).

2.2 Nanotechnologies – An introduction

As pointed out in the general introduction, nanomaterials are defined according to their size. In fact, they are particle compounds whose size ranges from 1 to 100 nm (nanometres[1]). They can be 1 million times smaller than a period and 80,000 smaller than a human hair (Raj et al., 2012) (see Figure 3). Nanomaterials can be both widely found in nature and engineered (i.e. designed for a specific purpose or function). Engineering nanomaterials enables to select materials to obtain desirable characteristics such as increased thermal and electrical conductivity and controlled release of host molecules (Matsoukas et al., 2015). Instead, examples of natural nanomaterials are casein micelles – the primary group of milk proteins – that are natural nanocapsules to deliver nutrients (Semo et al., 2007). Others are clay, silica, polymers, pigments and macromolecules that occur widely in nature in the nanoform (Calabia et al., 2010; Parisi et al., 2014; Parisi et al., 2015). Due to their unique physico-chemical properties, nanomaterials have been widely used in several sectors (EUON, 2017c). For example, in plastics and sport equipments they are extensively implemented to enhance chemical properties (e.g. heat resistance, hardness, durability). In coatings and paintings, to enhance the durability and to introduce new functionalities like antimicrobial resistance (same applies to textiles applications). In cosmetics, to improve the release of active substances and enhancing their properties (e.g. UV protection). In medicine, nanocarriers are used to deliver drugs and to fight cancer (Ferrari, 2005; Trafton, 2014).

Figure 3 - Size comparison between nanoparticle and other objects (EUON, 2017a).



In agriculture, most of the research at the R&D stage is focused on nanodevices aimed at optimizing agricultural production, especially in the application of agrochemicals (e.g. nanocarriers, nanoformulations, nanocapsules, nanosensors.) (Pérez-de-Luque, 2017). In this regard, nanomaterials are seen as a promising tool to promote the shift from conventional farming to precision farming. Thus, with the employment of controlled ant targeted release of agricultural input, both the amount of pesticides and fertilizers in the environment – and consequently the negative spillover effects on humans, environment and biodiversity – would be reduced, and the plant protection, growth and production would be enhanced (Khot et al., 2012). Table 2 summarizes the main nanostructures that can be employed in agriculture (de Oliveira et al., 2014; Khot et al., 2012; Mueller et al., 2012; Omanovic-Miklicanin & Maksimovic, 2016; Pérez-de-Luque, 2017). Examples of potential nanotechnology applications in agriculture are first, porous hollow silica nanoparticles (PHSN) that provide a shield protection *to pesticides from degradation by UV light* (Nair et al., 2010); second, hydrophobic nanosilica used as a targeted herbicide *to control a range of agricultural insects* (Nair et al., 2010); third, insecticide acephate nanoencapsulated in a PEG[2] surface establisher (Choudhury et al., 2012).

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[1] Equivalent to 10^{-9} metres.
[2] Hydrophilic polymer polyethylene glycol-400.

Table 1 – Overview of nanostructures employed in agriculture.

Nanostructure		Definition	Agricultural application
Nanomaterials		Material with external and/or internal dimension in the nanoscale	Plant germination and plant growth
Nanoformulations			Plant protection and plant production; controlled and targeted release of agrochemicals
	Nanoemulsions	Nano droplets containing two or more immiscible substances	
	Nanocontainers	Nanostructures that hinder direct contact of the substance they contain with unwanted tissues.	
	Nanoencapsulates	Nano droplets containing an active agent	
Nanosensors		Nano structures for the detection or determination of substances	Pesticides, fertilizers and pathogens detection
	biomarkers	Nanosensors specific for the detection of plant pathogens (e.g. bacteria, viruses, fungi)	Plant pathogens detection
	aptasensors	Nanosensors consisting of aptamers (i.e. molecules that bind to a specific targeted molecule)	Determination of pesticides and fertilizers
Nanocarriers		Nanostructure for smart delivery systems	Controlled and targeted release of agrochemicals

Although it is widely recognized that in sectors like cosmetics, plastics, paintings and food nanotechnologies are used, for their application in agriculture the information are scarce (EUON, 2017b; Kah & Hofmann, 2014; Parisi et al., 2015). This is mainly due to several regulatory uncertainties that will be covered in paragraph 2.5.1. Furthermore, due to their unique physico-chemical characteristics (i.e. chemical identity, particle characterization, transport behaviour, activity and reactivity) nanomaterials interaction – internal and/or external – with the environment and humans might have (eco)toxic effects (Seller et al., 2015). These negative effects and how nanomaterials might interact with both the environment and humans, are displayed in Figure 4 and Figure 5 in the next page, respectively. In this regard, concerns of environmental and human health risks are focused primarily on engineered nanomaterials as these are shown to be able and prone to cross cell barriers (Mueller et al., 2012). Finally, in the political and academic discourse, although it is general belief that nanotechnology applications in agriculture would bring economic and environmental advantages to both farmers and society at large (e.g. controlled slow-release of fertilizers and pesticides for a more sustainable primary production) (Boom, 2011; Siegrist et al., 2011), questions on whether nanotechnologies are possible to enhance the divide between low-, middle- and high-income countries are raised. This "nano divide" could potentially occur in the development stage – where rich countries are leader developers – and in the distribution stage – where the nanotechnology is applied in intensive farming systems enhancing the disadvantages of poor countries (Schroeder et al., 2016; Strand, 2011).

Figure 4 - Environmental hazards (Seller et al., 2015)

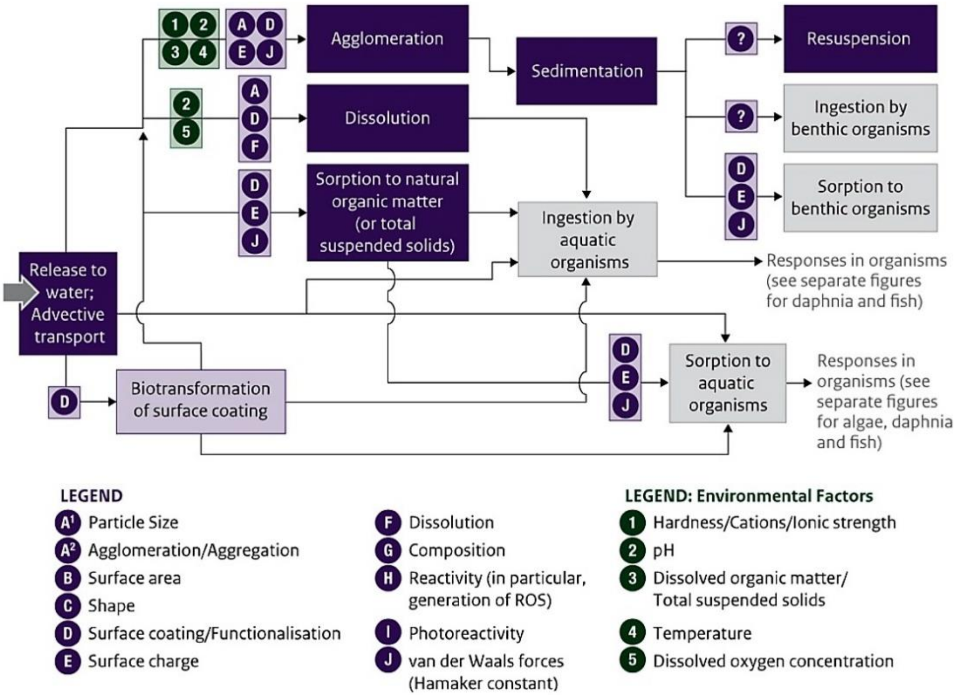
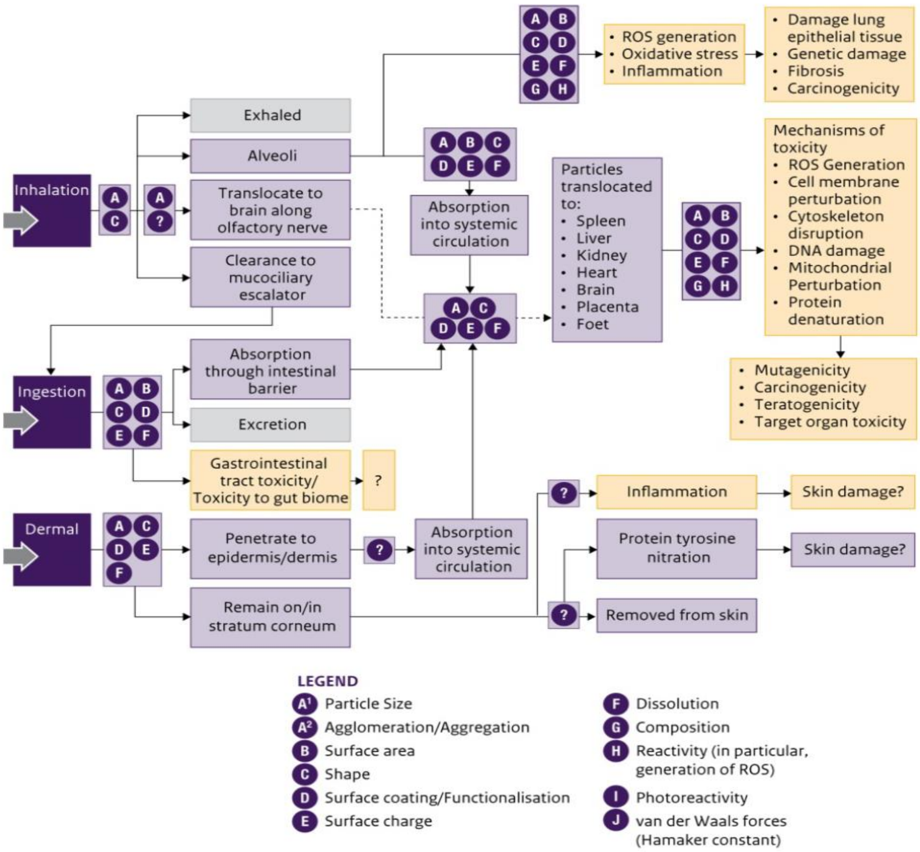


Figure 5 - Health hazards (Seller et al., 2015)



2.3 Risk assessment and risk management regulations for nanomaterials in the European Union.

The principal reason behind the need to regulate nanomaterials is that their physico-chemical properties vary from their bulk form (i.e. aggregate state), and thus may pose health and environmental risks (Dana, 2010; Seller et al., 2015). In Europe, Risk Assessment and Risk Management (RARM) frameworks are of primary importance in the development of new technologies in agriculture. This is to ensure high level of environmental and human health safety. "*Risk assessment always includes two aspects: hazard and exposure. Hazard is indicated by the toxicity of a given nanomaterial, while exposure is determined by the likelihood to come in contact with this nanomaterial"* (Mueller et al., 2012). At the European level, several are the institutions that deal with the risk assessment of nanotechnologies (i.e. the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), the Scientific Committee on Consumer Safety (SCCS), the European Food Safety Authority (EFSA) and the European Medicines Agency (EMA)) (European Commission, 2012a).

Specifically on nanotechnology applications as smart delivery systems for the targeted and controlled release of agricultural inputs, the European Chemical Agency (ECHA) has the role of assessing the risk and composition of chemical substances in order to protect human and environmental health, and at the same time it has to promote competitiveness and innovation. Several are the laws that regulate nanotechnologies, and these regulations consist of both horizontal and sector-specific legislation, where nanotechnologies are explicitly or implicitly addressed (Rauscher et al., 2017). The Regulation 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) and the Regulation 1272/2008 on Classification, Labelling and Packaging (CLP) are example of horizontal legislation. Both the REACH and the CLP regulations implicitly cover nanomaterials with the term "substances" in Article 3 (1) and Article 2 (7), respectively (European Parliament and the Council, 2006, 2008). Instead, with regard to biocidal products (e.g. pesticides, insecticides, repellents, etc.), the European legislation provides specific requirements for approval, depending on whether these products contain nanomaterials. In fact, as declared in the Regulation (EC) N 528/2012 on biocidal products (BPR), products that contain nanomaterials are not eligible for the simplified authorisation procedure, but have to be both approved with a separate risk assessment process and report nanomaterial presence in the label (European Commission, 2012b). Furthermore, specific and detailed explanations must be provided to justify *"the scientific appropriateness"* of the methods used to approved the introduction of nanomaterials as biocidal products (Rauscher et al., 2017).

2.4 The Responsible Research and Innovation (RRI) framework and its consequences in the development of new technologies

At the European level, programmes and action plans (e.g. Horizon 2020 and the Nanosciences and nanotechnologies Action Plan, respectively) are calling for research and innovation to be *responsible, integrated and safe*. To this aim, the European Research Arena (2008) published a Code of Conduct for Responsible N&N (Nanosciences and Nanotechnologies) providing specific recommendations to researchers regarding how they should behave while developing new technologies. Responsible Research and Innovation (RRI) is not a new concept but has received attention at the EU policy discourse only recently, in 2011, when Octavi Quintana, Director of the European Research Arena, was asking for help to properly define RRI to avoid *"misunderstandings and difficulties"* between science and society. On the basis of the detailed and globally used definition by von

Schomberg (2013)[3], the "Science with and for Society" EU Programme formulated a definition of RRI that became used at the European level and in the Horizon 2020 Programme: *"RRI is an inclusive approach to research and innovation (R&I), to ensure that societal actors work together during the whole research and innovation process. It aims to better align both the process and outcomes of R&I, with the values, needs and expectations of European society. In general terms, RRI implies anticipating and assessing potential implications and societal expectations with regards to research and innovation."* (Coles, 2014; European Commission). It is thus requested that the Research and Innovation process and the development of new technologies should be socially and ethically acceptable (i.e. respects the fundamental values and the normative targets of the EU), sustainable (i.e. does not undermine future generations in meeting their own needs), and socially desirable (i.e. the benefits are distributed among the society without discrimination) (Coles, 2014; Robinson, 2009). Furthermore, what is considered to be evolutionary is the dimension of responsiveness, that emphasizes the need, or better the ideal, to include all societal actors into the RRI process, where all these actors are mutually responsible. With RRI, science is not anymore "science in society", but "science for society" (e.g. focused on the "right impacts") and "science with society" (i.e. dimension of responsiveness) (R. Owen et al., 2012). However, this dimension of responsiveness, this goal of including all actors into the RRI process, may enhance the tension between the principle of participation and the principle of scientific freedom. R. Owen et al. (2012) stress that the models of science and innovation that are now being discussed and reshaped at the policy level are somehow changing the social contract of science, where *"scientific freedom is exchanged for the promise or expectation of socially-beneficial impacts"*, or, recalling von Schomberg, doing research and innovation in terms of "right impacts". These latter are intended as a political discussion, where the mechanism of anticipation is crucial (i.e. struggle to assess whether possible research and innovation processes may have unintended impacts) (Richard Owen, 2013). Although it is unclear what "responsible" means and what it refers to (i.e. is it a concept, a notion or a discourse, an approach, a strategy, an ideal, an aspiration? (Koops, 2015)), two main approaches can be distinguished: a product approach is used to develop framework and guidelines to make the research and innovation process more responsible (i.e. with tools such as the precautionary approach and risk assessment methods), while a process approach is used to make the procedure of innovation more responsible (i.e. innovating while being anticipatory, reflective, deliberative, and responsive) (Koops, 2015; Richard Owen, 2013; R. Owen et al., 2012)[4].

2.5 Uncertainties on European legislation

2.5.1 Inappropriateness and uncertainties of nanotechnologies regulations

All governmental bodies and the aforementioned legislation are based on the general definition of nanotechnology recommended by the European Commission: nanomaterial is "*A natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm - 100 nm. In specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50 % may be replaced by a threshold between 1 and 50 %"* (European Commission, 2011). One of the major problem with this definition is that it does not specify whether the technology is engineered (i.e. manufactured on purpose) or occurring naturally. In fact, as specified in

[3] *Responsible Research and Innovation is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society.*).

[4] *Anticipatory*: try to forecast unintended and potentially negative consequences that could be arise. *Reflective*: reflect on the purposes of the research and innovation process, considering their final outcomes. *Deliberative*: engage in collective deliberation and dialogue processes with stakeholders in the research and innovation process to get a broader range of perspectives. *Responsive*: take societal and ethical aspects into account to better frame the research and innovation process.

paragraph 2.2, nanomaterials are widely present in nature. Furthermore, as pointed out by Mueller et al. (2012), concerns regarding health and environmental risks focus mainly on engineered nanomaterials as they are shown to be able and prone to cross cell barriers. Moreover, the definition does not consider nanomaterials volume. As stressed by Parisi et al. (2014) there is a strong difference between measuring the number of particles and their volume: "*recipe that contains 0.1% nanoparticles by volume can contain ≈ 99.9% nanoparticles by number.*" Thus, it is likely that the threshold of 50% in particle number size distribution is exceeded. Finally, Kah and Hofmann (2014) argue that while 100 nm as an upper threshold would exclude recent nano formulations, microemulsions already existing on the market since 1990s exhibit nano behaviour. In light of this, Salvi (2015) points out that it is questionable whether a coherent regulatory framework could be developed as the definition of nanotechnology is not generally accepted and does not take into consideration the wide range of nanomaterials unique physico-chemical properties. Hence, this is translated in difficulties and challenges for both for researchers and companies that have to assess whether a technology shall be labelled as nano or not, and whether existing products containing nanomaterials should undertake the *ad hoc* risk assessment procedure (Parisi et al., 2014). This is exacerbated by the fact that, as highlighted by the EUON (2017b), under the REACH are present several uncertainties. First, nanomaterials are not explicitly covered and thus there is no obligation to report them. Moreover, nanomaterials are included by the term "substance". Under the REACH a substance is defined as a chemical compound in its natural state or manufactured. However, nanomaterials can be present in two or more compounds and thus are not defined as a substance and subsequently would be excluded by the REACH regulation. Second, measuring whether a substance is in the nanosize is extremely costly and if there is no legal basis to perform a test, this might not be performed by the manufacturer. Third, under the REACH a substance must be registered if it exceeds the 100 tonnes of production per year. Consequently, substances which total production is under the 100 tonnes could be already on the market. However, it is noteworthy that the total annual production of nanomaterial per producer is estimated to be approximately 750 kg per year (Brosset, 2013). Hence, the 100 tonnes threshold would not be reached. Last but not least, not only developing nanotechnologies costs 10 to 1000 times more than currently used composites (Lauterwasser, 2005), but also the *ad hoc* risk assessment – that should be accomplished *if* the technology is in the nano form – is highly costly. Choi et al. (2009) have shown that depending on four levels of testing (i.e. optimistic, neutral, risk averse and precautionary) the total estimated costs of risk assessment for nanomaterials under the REACH ranges between 249 million euro and 1.2 billion euro.

2.5.2 Ambiguities on the recommendations to conduct a RRI process

The recommendations to conduct a RRI process present several ambiguities. First, as Blok and Lemmens (2015) argue, the two recommendations of solving grand challenges and developing a technology that is socially desirable are linked from finding a consensus about the definition of the problem and thus about the scope of the technology. However, as Rittel and Webber (1973) pointed out, the formulation of the problem to solve grand challenges – also called wicked problems – depend on individuals' ideas to resolve it. Thus, different actors might have different goals and may take different societal and ethical aspects into account. Furthermore, *"we have come to realize that the concept of the social product is not very meaningful; possibly there is no aggregate measure for the welfare of a highly diversified society,[…]."* (Rittel & Webber, 1973). It is thus clear, that while in principle developing a nanotechnology that benefits the society without discrimination can be considered as an optimal achievement, in practice this is unlikely to occur. Second, with regard of involving the society and explaining to the public researchers' activities, Besley and Nisbet (2013) report that researchers and experts perceive the public as not willing to become more knowledgeable. Moreover, it was also reported that scientists believe that the public is neither informed nor inclined to trust the scientific community. This is argued to have had an impact on the acceptance of several technologies (i.e. stem cells and genetic modification). In addition to this, Besley and Nisbet (2013) also reported that scientists are concerned that the public will misunderstand any communication attempt. Third, in relation to the dimension of responsiveness (i.e. all the stakeholders are mutually responsible) several observations can be made. Although this dimension is based in accordance with the precautionary principle, where researchers need to anticipate possible negative effects on humans and environment to ensure an innovation process that is safe, ethical and sustainable (European Research Arena, 2008), the actors involved will hardly find a desirable outcome for a technology and they will not likely be responsible for that outcome (Blok & Lemmens, 2015). In addition to this, they also pointed out that the innovation process is uncertain *per se*, where the social outcome of a technology cannot be predicted (i.e. Collingridge dilemma) and the technology may be used in a way that was not intended in principle (i.e. Jevons Paradox). Moreover, in the European Research Arena (2008) Code of Conduct for Responsible N&N – Nanosciences and Nanotechnologies – it is stressed that the researchers, and not other actors, should be held responsible for the outcome of the technology they develop. Thus, *a fortiori*, the dimension of responsiveness can be highly questioned. Fourth, transparency is also believed to be a pillar for reaching a more democratic decision-making process (von Schomberg, 2012). However, information asymmetries are source of competitive advantage and that is why it is argued that *"the call for transparency of innovation process is highly naive."* (Blok & Lemmens, 2015). Finally, as Davies and Horst (2015) have pointed out, discussions over the concept of responsibility are more in the academic research arena than in practice, where scientists do not seem involved in this discussion in their own practice.

2.6 Main hypotheses

Following the arguments discussed in the paragraphs above, three hypotheses are formulated:

I. Researchers and experts do not consider appropriate the European definition of nanotechnologies;

II. The Risk Assessment and Risk Management frameworks are believed to constrain the development and commercialization of nanotechnologies in agriculture;

III. The recommendations to conduct a RRI process will be more supported by experts and more disapproved by researchers.

2.7 Interest groups in EU policies

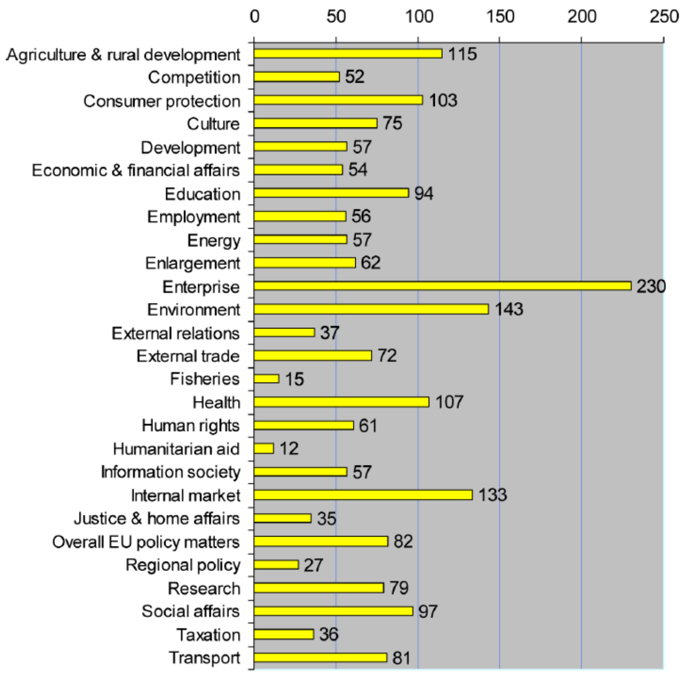
Although interest groups are not one of the main focus of this research, they are important actors influencing the introduction of new technologies in agriculture. This is why in this study researchers and experts' opinions on whether and how NGOs influence the development and commercialization of nanotechnologies in agriculture were also investigated. Hereafter is explained why interest groups are considered important in shaping societal awareness and ideas with regard to the introduction of new technologies in agriculture.

"Lobbying can impact on the first, second and third dimensions of power – by shaping decisions that are taken, by ensuring that some decisions are never taken, and by shaping the culture and the consciousness of actors to ensure that some issues are not recognized as being those for which decisions should be taken." (Svendsen, 2011).

Interest groups activities at the European level are spread on almost all sectors, especially in enterprise, environment and agriculture (Figure 6) (Coen, 2007). Knill and Tosun (2012) define two different interest groups: public and private. The formers seek to affect the policy making process to pursue specific preferences of their

members. Instead, the latter seek to pursue “common” goals. As argued by Tortajada (2016), although NGOs are seen as public interest groups, they do not always prioritize societal and environmental concerns, but their own ideologies and interests. Thus, NGOs can be considered as both public and private interest groups.
Gostin and Hodge (2007) reported that private interest groups greatly exert their influence in shaping policies for nanotechnologies applied to medicine. With respect to agriculture, and more specifically to nanotechnologies, private interest groups wield their leverage through associations that mainly provide information, like the NIA – Nanotechnology Industries Association (NIA). The NIA comprise 35 companies and it promotes nanotechnologies safety and their reliable advancement.

Figure 6 - Interest groups by policy area (Coen, 2007)



Although it is not part of the main research objectives of this study, it was interesting to assess NGOs influence in the development and commercialization of nanotechnologies in agriculture.
In order to understand how NGOs gained power at the European level, we should go back to 1990 with the introduction of GMOs. The Directive EC 90/220 was enacted to establish the procedures for the introduction of GMOs in Europe. This procedure provided for the qualified majority voting by the European Council of environmental ministers (European Commission, 1990). NGOs started to hardly criticize this directive advocating that Member States should have had their own sovereignty on the matter and no decisions should have been imposed. After several years of campaigns and strong debates, the 1990 directive was replaced by the Directive EC 2001/18 that established a new, more complex decision-making process where public consultation and participation were considered fundamental to reach consensus over GMO regulation (European Commission, 2001). Although the goal was to enhance public opinion towards a more homogeneous perception on the technology, *de facto* this did not happen. On the other hand, it was effective in increasing NGOs lobbying capacity in the European decision-making process (Dür, 2008; Rouchier & Thoyer, 2006). The approval of the Directive EC 2001/18 was just a springboard of NGOs reputation. One of the underlying principles of public interest groups credibility is that their societal trust is built upon both their battle against corporation. Moreover, this was facilitated by their own nature: being non-profit. In this way, NGOs have gained substantial power not only in Europe, but in the whole world. Particularly, the Cartagena Protocol and the introduction of the Precautionary Principle signed the beginning of anti-GMO campaigns from the United States to African countries (Karembu, 2017; Paarlberg, 2014). While in the former several food crops were driven off of the market (e.g. wheat, rice, potato and

melons)(Paarlberg, 2014), in the latter the majority of the States put a ban on genetically modified grains imports (e.g. Kenya) or on cultivating GM crops[5] – voluntarily or according to the law – (Karembu, 2017). Thus, NGOs were successful in shaping the culture and consciousness of the society: GMOs have become to represent the negative aspect of modern agriculture and have tended to be considered as amoral (Bartsch, 2014).

However, the history seems to repeat itself: by the end of 2007, due to uncertainties regarding health and environmental risks of nanotechnology applications, several NGOs started to advocate a precautionary approach, and some also asked for a *moratorium*. ELSA (i.e. Ethical, Legal, Social Aspects) and HES (i.e. Health, Environment, Safety) were emphasized and with the increase of societal concerns, these were forced into the political discourse (Robinson, 2009). In this regard, Gostin and Hodge (2007) pointed out that NGOs pressures have several repercussions, from questioning public safety to weaken societal trust in governments and science. In addition to this, Robinson (2009) stressed that NGOs activities can unlock previous lock-ins, where earlier governance arrangements collapse. Hence, it is argued that NGOs have a strong power in determining the success or unsuccess of a technology. It was thus considered relevant to assess how researchers and experts perceive NGOs role surrounding the development and commercialization of nanotechnologies in agriculture.

[5] With the exception of South Africa, Sudan and Burkina Faso.

Chapter 3 – Methodology

This study wants to investigate what researchers and experts' perceptions are towards the European legislation for the development and commercialization of nanotechnologies in agriculture. In order to do so, a web survey was designed in which the population chosen is composed of private and public researchers and experts that work with biotechnologies. There are two main reasons for using an online questionnaire. First, because it represents an efficient and valid method to be applied in the social sciences for analysing stakeholders perceptions (Frippiat et al., 2010). Second, because it is an efficient method to gather primary data on the population. This also represents one argument explaining why web surveys became frequently used by researchers in several field: from social sciences (Keusch, 2015; Lappalainen et al., 1998) to medicine (Sapienza et al., 2009). In addition, in the last two decades they have become one of the most used type of survey due to their time-saving and non-costly characteristics (Dodou & de Winter, 2014; Petrovčič et al., 2016).
For the purpose of this study, the population taken into consideration was gathered from several databases[6]. These databases included contacts of the individuals that have participated in conferences and workshops related to biotechnology, nanotechnology and food. In this way, the likelihood of having a population with familiarity with agro-nanotechnologies was greater. Once the contacts have been collected and the duplicates removed, the final population summed up to 4193 individuals.

In the following paragraphs it will be firstly explained the choice of the socio-economic, demographic and background knowledge variables considered relevant for the purposes of the research (i.e. gender, age, marital status, having children, employment, country membership, nano knowledge, RARM & RRI familiarity). Then, it will be explained how the survey was structured, and how data were collected. Finally, the statistical methods (i.e. parallel analysis, factor analysis and cluster analysis) are defined and justified.

3.1 Demographic and socio-economic variables, and background knowledge of respondents

As stressed by Moerbeek and Casimir (2005), environmental and health risks derived from introduction of new agri-food technologies play a determining role in affecting individuals' attitudes towards food. Moreover, these attitudes vary depending on individual characteristics. This is why demographic, socio-economic characteristics and background knowledge of respondents (i.e. gender, age, marital status, employment, having children, country membership, nanotechnology knowledge, RARM and RRI familiarity) were used as control variables in the analysis.

Gender and age

Several studies highlighted that *gender* affects risk perception. For example, Byrnes et al. (1999) and Dohmen et al. (2011) showed that men seem to be overall less risk averse than women. In addition, Moerbeek and Casimir (2005) found the evidence for a gender effect on GMOs acceptance. In fact, they showed that women are

[6] AMIS Global Food Market Information Group, Bio Okonomie Congress, Der Projektträger Jülich, Die Lebensmittelwirtschaft, GMCC – The International Conference on Coexistence between Genetically Modified (GM) and non-GM based Agricultural Supply Chains, ICABR - The International Consortium on Applied Bioeconomy Research, Inbiosoil Symposium, JRC – Nanotechnology for the Agricultural Sector: from Research to the Field, JRC – The global pipeline of GM crops: an outlook for 2020, Synenergene Conference, The CAP post 2013 – Conference on the public debate, WHO – Round table on access to information, public participation and access to justice regarding LMOs/GMOs, WHO – Working Party on Agricultural Quality Standards (WP.7).

less willing to accept GMOs than men, thus being more risk averse. Furthermore, regardless the topic, risk aversion is correlated to the amount of testosterone: the higher the testosterone, the higher the risk tolerance (Sapienza et al., 2009).
As the population chosen is composed of private and public researchers and experts that work in the biotechnology sector, the age of the population should vary between 24 to over 65 years old (it is unlikely that lower aged individual already has a researcher position). The degree of risk perception and tolerance is not only given by gender differences, but also determined by the individuals' age. Donkers et al. (2001) displayed how both women and older people are less risk tolerant. Similarly, Harrison et al. (2007) showed that individuals between 40 and 50 years old are more risk tolerant than individuals both younger than 30 and older than 50 years old. Same conclusions are also drawn by Donkers et al. (2001) and Hartog et al. (2002). However, risk perceptions was never analysed directly in relation to nanotechnologies. Thus, it is interesting to see if previous studies confirmed these trends for the latter.

Marital status and having children

In addition to the variables discussed above, *marital status* also plays a significant role in determining the degree of which individuals are risk tolerant. Hanewald and Kluge (2014) showed that individuals in married couples share their level of risk tolerance, which leads to a homogenisation of their risk attitudes. Married couples were also shown to be less risk tolerant with respect to non-married individuals. More specifically, Hartog et al. (2002) displayed how single parents, single individuals and partners that live together are more risk tolerant than married couples. Furthermore, Hanewald and Kluge (2014) found that the presence of child(ren) above 18 years old lead individuals to be more risk averse than subjects with child(ren) below 18 years old. In another study, Dohmen et al. (2011) concluded that risk aversion in general increases with the condition of having children. To conclude, it has however to be mentioned that correlations between risk perceptions and marital/children status were never specifically studied in relation to nanotechnologies. Giving all these findings, marital status and the fact of having children were asked in the web survey.

Country, employment and background knowledge

Due to incomplete information about individuals in the databases, several questions were posed in the survey about working country, type of employment and background knowledge on nanotechnologies and their legislation.

First of all, as this study focuses on the influence of European legislation on the development and commercialization of agro-nanotechnologies, in the survey it was asked in which country the respondents are currently working. Moreover, as the development of nanopesticides is a main field of application of nanotechnologies in agriculture (Chhipa, 2017), this is a relevant question since people from different countries were shown to have different risk perceptions of pesticides (DG COMM, 2009).

Second, given that this study also wants to detect eventual different opinions on nanotechnology regulation between scientists and experts, occupation type of respondents was asked in the survey. Because of the drawbacks of the RRI process as it is currently intended (see Paragraph 2.4), it is expected that respondents will have different ideas on both goodness and utility of the RRI framework.

Finally, respondents' familiarity with nanotechnologies and their legislation was not indicated in the databases. Thus, they were asked about their knowledge on nanotechnologies in agriculture, and on the European regulatory frameworks (i.e. RRI and risk assessment and risk management – RARM). This allowed to understand whether, and how, individuals with different expertise responded differently in the web survey. The latter is important since Finucane et al. (2000) stresses that risk perceptions depend on the information that an individual has. It is thus assumed that respondents with different expertise and familiarity level will have different attitudes and perceptions towards European legislation.

3.1.1 Sub-hypotheses

Giving the influence that the background variables above-reported have on respondents' perceptions, the following sub-hypotheses in addition and related to the main hypotheses in paragraph 2.6 were formulated:

i. Respondents who are male, young, not married and without children are more risk tolerant. This is translated into the expectation of more disapproving opinions towards both the risk assessment and risk management regulations and the recommendations to conduct a RRI process;

ii. Risk assessment and risk management regulations, as well as responsible research and innovation recommendations are differently assessed depending on geographical region and employment type;

iii. Respondents' opinions on risk assessment and risk management regulatory frameworks and on recommendations to conduct a responsible research and innovation process are different depending on individuals' knowledge on nanotechnologies and on their familiarity with RARM and RRI frameworks.

3.2 Survey design

The web survey was designed using *Qualtrics* software. The online questionnaire consisted of thirty-one questions and was structured in six parts (Background information, European definition of nanotechnologies, Risk assessment and risk management frameworks, Responsible Research and Innovation framework, Relation between GMOs and agro-nanotechnologies, More general questions on agro-nanotechnologies). Appendix I shows the whole questionnaire.

The first section investigated background information (i.e. socio economic, demographic and knowledge characteristics regarding the different topics considered in the study). These information were fundamental to assess whether, and how, respondents with dissimilar characteristics responded in a (significant) different way to the questions posed in the web survey.

The second and third sections covered the legislation behind the characterization of nanotechnologies (i.e. their definition) and at the base of their safety measures (i.e. risk assessment and risk management frameworks). These questions were asked to understand whether this laws were considered well suited for the development and commercialization of nanotechnologies in agriculture (e.g. nanoencapsulated pesticides, fertilizers, etc.). Furthermore, section three investigated also whether NGOs are negatively affecting the advancement of nanotechnologies.

The fourth section explored individuals' opinions on the Responsible Research and Innovation (RRI) framework recommended by the European Union. In particular, it was investigated to what extent respondents agree with each of the guidelines included in the current code of conduct for responsible Nanoscientists. Moreover, it was also asked how the RRI process is effectively encouraged by the institution where they work. Finally, a last question tried to assess whether the development of nanotechnologies is concretely influenced by the RRI process.

The fifth section was designed to understand if the widespread criticism and blockage of GMOs is likely to occur, and how, also with respect to agro-nanotechnologies applications.

Finally, the sixth section included general questions about the development and commercialization of agro-nanotechnologies. In particular, it was studied to what extent respondents think that some of the aspects dealt in the previous sections (lack of communication between science and society, inadequate regulations, NGOs campaigns, attitudes towards GMOs and nanotechnologies risks) are impeding both the development and commercialization of agro-nanotechnologies. The chosen aspects allow to assess the relative importance in affecting nanotechnology development and commercialization of all the topics dealt in each previous section. In addition, the last two questions of this section intended to understand possible reasons why agro-nanotechnologies are not commercialized yet and whether their introduction can increase the divide between low-, middle- and high-income countries.

3.3 Data collection

For the first section, all the questions were categorical (nominal) variables (i.e. they have two or more categories and these do not have an intrinsic ordering – for example, the nominal variable *Gender* has two categories: female and male). For the other five sections, questions were ordinal variables (i.e. they have two or more categories, but these do have an intrinsic order). For each of the six sections, the questions were based on different scales. On the one hand, a seven-point Likert scale accounted for a rating from *strongly agree* (1) to *strongly disagree* (7), a rating from *extremely appropriate* (1) to *extremely inappropriate* (7), and a rating from *extremely increase* (1) to *extremely decrease* (7). On the other hand, a nine-point Likert scale accounted for a rating from 0 to 9 in which 1 stands for *not at all*, 5 stands for *neutral*, 9 stands for *extremely*. In all these questions, the opt-out option was set as 0, that corresponded to *not sure*. The questions related to concepts of familiarity had a five-point rating scale from *extremely familiar* (1) to *not familiar at all* (5). Finally, the survey also included two open-ended questions, to let the respondents giving their personal opinion on what is a RRI framework and how it is encouraged in their work environment. In addition, it was also asked how a GMO scenario is possible to occur to agro-nanotechnologies. This was intended to have a better and broader understanding on what the individuals' points of view are.

The online questionnaire was sent two times, the second one being a remainder one week after the first one. Some of the respondents forwarded the questionnaire to their peers, increasing the overall number of individuals from 4193 to 4212. Of these, 330 individuals started the survey and 151 completed it. The completion rate was then 47.8%, and the response rate 3.6%. Collected data were then exported to IBM® SPSS Statistics® and to Stata® to be statistically analysed. In SPSS all the variables except the nine-point Likert scale were reverse scaled (e.g. the seven-point Likert scale from *strongly agree* (1) to *strongly disagree* (7), was changed into a rating from *strongly disagree* (1) to *strongly agree* (7)). In this way, all the responses had the same logical reasoning. In addition, to be more easily interpreted, the seven-point Likert scale was condensed to five (*disagree, somewhat disagree, neither agree nor disagree, somewhat agree and agree*) and the nine-point Likert scale was condensed to seven *(not at all, moderately -, slightly -, neutral, slightly +, moderately +, extremely*, where "-" and "+" stand for negative and positive, respectively).

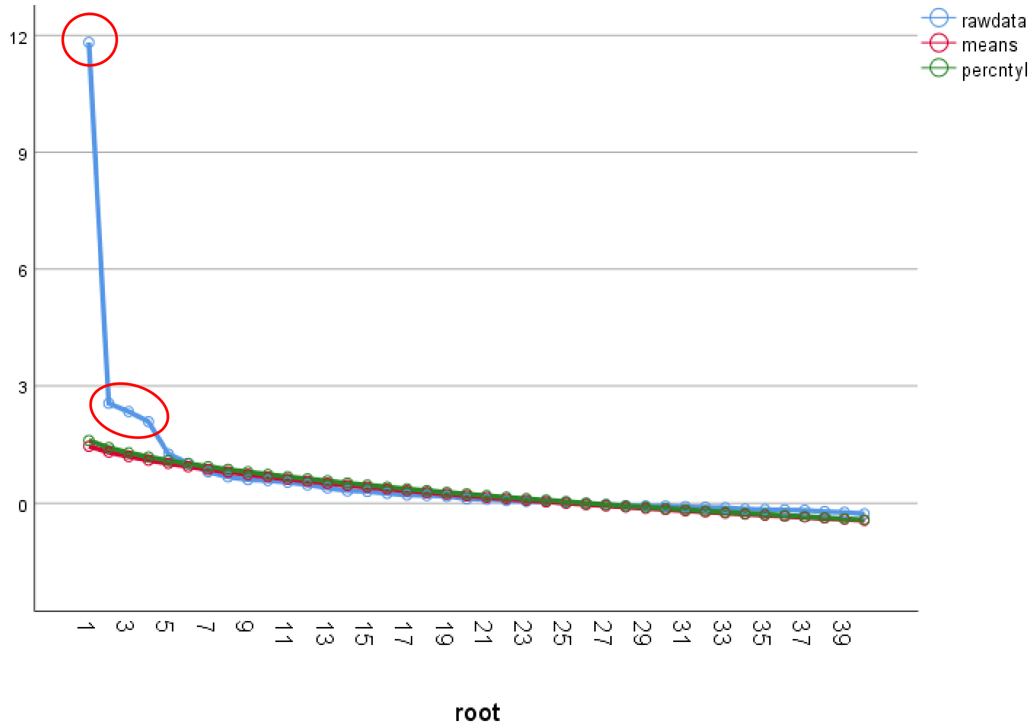
3.4 Data analysis

As aforementioned, data were analysed using IBM® SPSS Statistics® and Stata® (version 25 and version 10, respectively). First, a Monte Carlo simulation – also known as parallel analysis – was run to determine the number of statistically significant eigenvalues (i.e. the variance of the associated factor out of the total variance), to be considered in the subsequent factor analysis. The factor analysis was then performed to capture respondents' perceptions over the RARM regulations and nanotechnology definition, the RRI framework recommended by the European Union, and how respondents perceive NGOs activities and likelihood of a recurrence of a GMOs scenario for agro-nanotechnologies. Finally, a K-means cluster analysis was computed to group respondents with similar characteristics and perceptions into the same cluster.

3.4.1 Factor analysis

First of all, a Monte Carlo simulation was performed to the determine the number of significant factors to be considered in the factor analysis. This analysis creates a random dataset based on the original data, and then computes a correlation matrix in which the eigenvalues are calculated. The values are then reported in a scree plot (i.e. graphical representation of the variance that accounts for by each eigenvalue, or factor, from the largest to the smallest) (see Figure 7). Factor analysis eigenvalues larger than parallel analysis eigenvalues can be kept (the other values are mostly considered as random noise) (Franklin et al., 1995). As can be seen from the figure below, the number of eigenvalues to be retained summed to four.

Figure 7 - Monte Carlo simulation based on the original dataset.



Subsequently, a factor analysis was computed. Factor analysis allows to identify latent common factors (i.e. sources of variance common to two or more variables that cannot be directly measured) and explain their relationship to the observed data (Lattin et al., 2003). Although both principle component and factor analysis reduce the dimension of the data, principle component analysis is focused on re-expressing the data, in which each component is the linear combination of the original variable. The latent common factors cannot be measured by a single variable (like in principal component analysis), but they are given by the relationship they cause in a set of variables (Suhr, 2005). Since this study wants to measure behavioural traits (i.e. researchers and experts' perceptions towards the European legislation, NGOs activities and GMOs "inheritance"), it was assumed that there were latent constructs shared between the original variables. After choosing the significant number of factors to retain and the method to apply, other two important decisions had to be made: the factoring method to use and which factor rotation. First, as the assumption of multivariate normality was violated, the factoring method chosen (i.e. the extraction method) was *principal axis factoring*. This is appropriate to identify latent constructs because it extracts the maximum variance, reducing the number of variables into a smaller number of factors (Gie Yong & Pearce, 2013). Second, the factor rotation implemented was *direct oblimin*. This is an oblique rotation, as it assumes that there is correlation among factors. Following Brown (2009), a factor analysis with four factor solution and *direct oblimin* rotation was initially performed. Then, the output of the factor correlation matrix was inspected to see whether the correlations between the factors exceeded 0.32 (in absolute value) – in this case correlation is assumed as *"there is 10% (or more) overlap in variance among factors"* (Brown, 2009). The output showed that the correlations were around and above 0.32, warranting the choice of using an oblique rotation (see Figure 8).

Figure 8 - Factor correlation matrix.

Factor Correlation Matrix

Factor	1	2	3	4
1	1.000	.382	.329	-.345
2	.382	1.000	.240	-.237
3	.329	.240	1.000	-.230
4	-.345	-.237	-.230	1.000

Extraction Method: Principal Axis Factoring.
Rotation Method: Oblimin with Kaiser Normalization.

To perform the following analysis, factor scores (i.e. composite variables that provide information on individuals' position in the factor) were saved with *Bartlett* method. This method allowed to obtain scores that were highly correlated with their corresponding factor. Moreover, as Bartlett saving method was computed with ML (i.e. Maximum likelihood) statistical procedure, it produces unbiased estimates of the true factor scores (DiStefano et al., 2009).

3.4.2 Cluster analysis

Cluster analysis involves grouping variables so that the observations within groups are relatively similar and observations between groups are relatively dissimilar. There are two main clustering methods: hierarchical and non-hierarchical. Hierarchical clustering relies on measuring proximity between observations, thus creating cluster solutions that are nested from smaller to larger clusters, or *vice versa* (depending if the approach is bottom-up or top-down) (Lattin et al., 2003). Instead, non-hierarchical clustering methods do not rely on hierarchical relationships between clusters, but separate observations into a pre-determined number of clusters so that the observations within groups are relatively similar and observations between groups are relatively dissimilar. In the study, a *k-means* clustering algorithm was chosen to efficiently find out only locally optimal solutions as the ESS (i.e. error sum of squares of the partition) were minimized. To choose the significant number of clusters, a *pseudo-F-statistics* – also known as Calinski-Harabasz F test or Calinski stopping rule – was performed with Stata® (version 10) (see Appendix II). As this test is the ratio of the mean SSB (i.e. sum of squares between groups) to the mean SSW (i.e. sum of squares within groups), the larger the *F-statistics*, the higher the within-group homogeneity (Caliński & Ja, 1974; Lattin et al., 2003). The Calinski-Harabasz F test showed that the highest pseudo-F index (65.85) corresponded to two clusters. Therefore, a k-means cluster analysis was performed. However, with the two-cluster solution, Cluster 1 had 117 observations and Cluster 2 had 29. The allocation of observations among the clusters was therefore highly uneven, since Cluster 1 included almost all respondents' perception. In this way cluster analysis resulted meaningless, as it did not provide an efficient grouping of the respondents in order to detect differences in their opinions. Thus, a k-means cluster analysis was performed with five clusters, according to the second highest pseudo-F index (56.76).

Chapter 4 – Results

The purpose of this study is to explore and understand what researchers and experts' perceptions are towards the European legislation for the development and commercialization of nanotechnologies in agriculture. To round out the comprehension of researchers and experts' perceptions, this study tried to answer to the research questions on paragraph 1.2.2. To this aim, the main hypotheses formulated in paragraph 2.6 and the subsequent hypotheses in paragraph 3.1 were tested. All these hypotheses are re-stated below.

Main hypotheses

I. Researchers and experts do not consider appropriate the European definition of nanotechnologies;

II. The Risk Assessment and Risk Management frameworks are believed to constrain the development and commercialization of nanotechnologies in agriculture;

III. The recommendations to conduct a RRI process will be more supported by experts and more disapproved by researchers.

Sub-hypotheses

i. Respondents who are male, young, not married and without children are more risk tolerant. This is translated into the expectation of more disapproving opinions towards both the risk assessment and risk management regulations and the recommendations to conduct a RRI process;

ii. Risk assessment and risk management regulations, as well as responsible research and innovation recommendations are differently assessed depending on geographical region and employment type;

iii. Respondents' opinions on risk assessment and risk management regulatory frameworks and on recommendations to conduct a responsible research and innovation process are different depending on individuals' knowledge on nanotechnologies and on their familiarity with RARM and RRI frameworks.

4.1 Influence of background information on respondents' perceptions on European legislation

To understand opinions and perceptions just among respondents who expressed a judgement, each variable (i.e. each question) was statistically analysed excluding the opt-out option as answer. To this aim, the variables without the opt-out option were generated in SPSS (see Appendix III – Table 1c and 1d). Leaving the opt-out option would have biased the mean response for each variable, considering that *Not sure* (i.e. the opt-out option) had a score of 0. Percentages of *Not sure* are moderately high (ranging 24.5% to 33.1%) in the first three survey sections (European definition of nanotechnologies, risk assessment and risk assessment frameworks, NGOs activities), while they are much lower (6-15.9%) in the remaining ones (responsible research and innovation framework, relation between GMOs and agro-nanotechnologies, general questions about agro-nanotechnologies). Only in two questions values were particularly high: 23.8% in respondents' perceptions towards a possible increase in the divide between low-, middle-, and high-income countries after nanotechnology introduction, and 49% in relation to individuals opinion on whether the innovation process has changed in practice after the introduction of the recommendations to conduct a RRI process. According to what mentioned so far, all the values reported in the next paragraphs with regard to respondents' answers relate to the values in Appendix III table 1d, except for those variables that did not include the opt-out option among the possible answers (i.e. background information, that refer to Appendix III Table 1c).

To have a graphical interpretation of the data, in the next page it is reported a graph representing the mean response of individuals for each question in the questionnaire (see Figure 9). The light-blue bars relate to 5-point Likert scale questions, while grey bars to the 7-point Likert scale ones. Errors bars correspond to the S.E of the mean.

4.1.1 Descriptive statistics of the sample

Background information.

First of all, the descriptive statistics (i.e. frequency, mean and standard deviation) were inspected to identify respondents' socio-economic and demographic characteristics (see Appendix III, Table 1a). Most of the respondents were males (72.2%), married (74.2%) and with children (70.9%). While no respondent had less than 25 years old, the 80.1% of them was homogeneously distributed among the different age ranges (35-44, 45-54, and 55-64 years old). Relevant for the purpose of this study is that most of the respondents were working in Europe[7] (62.3%), and that the population targeted (public and private researchers and experts) accounted for 79.4%[8]. Furthermore, within Europe most of the respondents were from Germany and Italy (11.3% and 7.3% respectively), followed by Belgium, the Netherlands, Switzerland, and the United Kingdom (9% each).

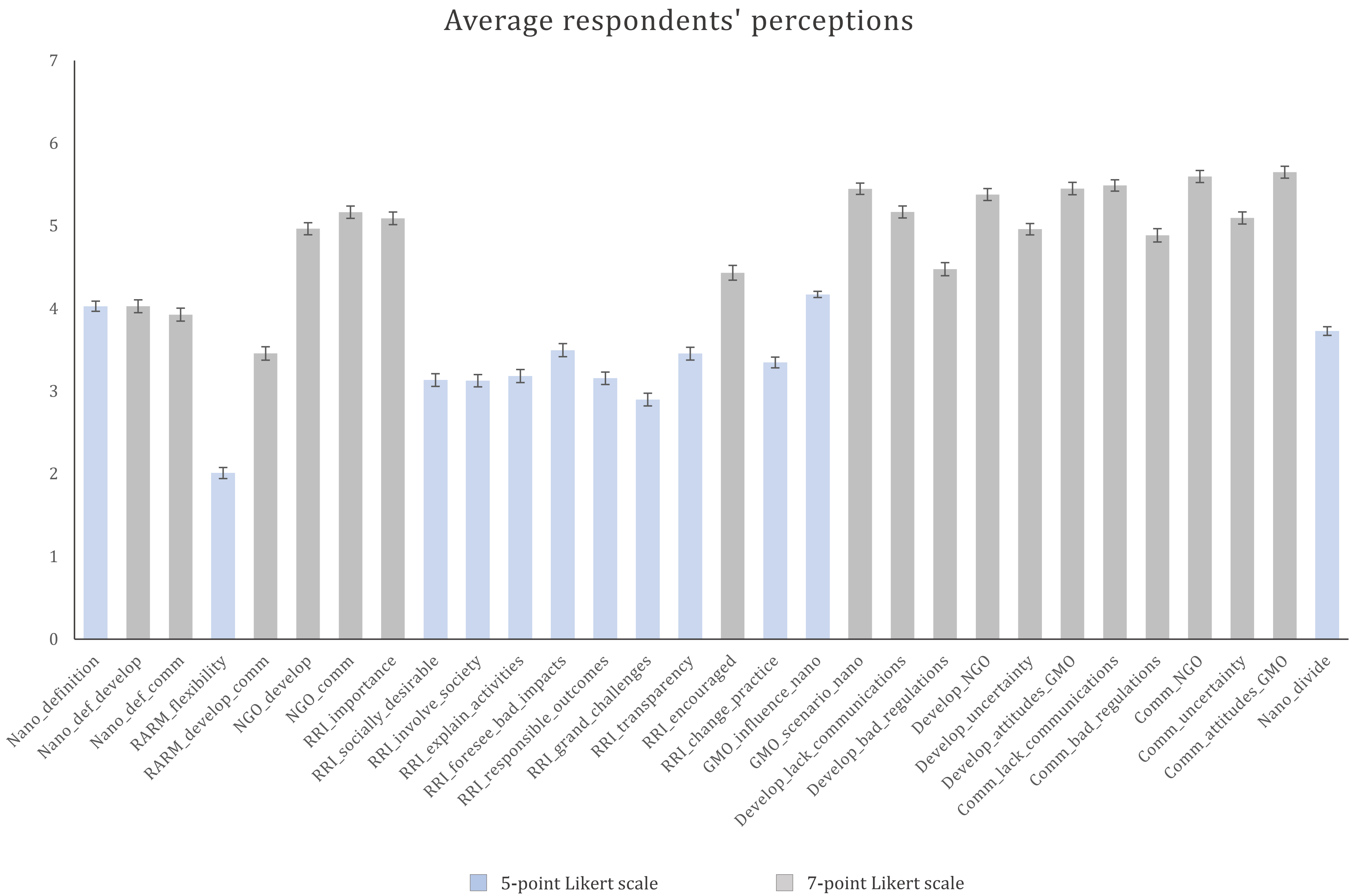
Concerning background knowledge of the sample (i.e. knowledge on nanotechnologies, familiarity with RRI and RARM), 69.6% of the individuals had a *poor-average* knowledge on agro-nanotechnologies (see Appendix III, Table 1b). With regard to respondents' familiarity with the risk assessment and risk management framework, 15.2% and 40.4% of the sample was not familiar at all with RARM and RRI, respectively, which is remarkable.

Answers to the questions in the survey.

After having identified sample background characteristics, descriptive statistics of survey responses were investigated (see Appendix III, Table 1c). From the first section, *"European definition of nanotechnologies"*, it unexpectedly turned out that the definition of nanotechnology was highly accepted among the respondents (75% of them indicated that the definition is *slightly appropriate* or *appropriate*). The average response resulted to be 4.03 out of 5 (see Figure 9). In particular, Wilcoxon signed-rank test (see Appendix III, Table 2a) showed that the shift towards values higher than 3 (which indicates neutrality condition) was significant (P<0.001), meaning that respondents significantly agree on the acceptability of the nanotechnology definition. Therefore, the test did not confirmed the first main hypothesis (i.e. researchers and experts do not consider appropriate the European definition of nanotechnologies). Although the definition is widely accepted, the effects it has on the development and commercialization of nanotechnologies are not interpreted univocally. In fact, while around 40% of the respondents perceived the European definition to lay the foundations for a regulatory framework capable of incentivizing the advancement of the technology, the other 40% believed otherwise.

[7] European Union, EFTA Member States.
[8] In Europe the percentage of public and private researchers and experts summed to 60.8.

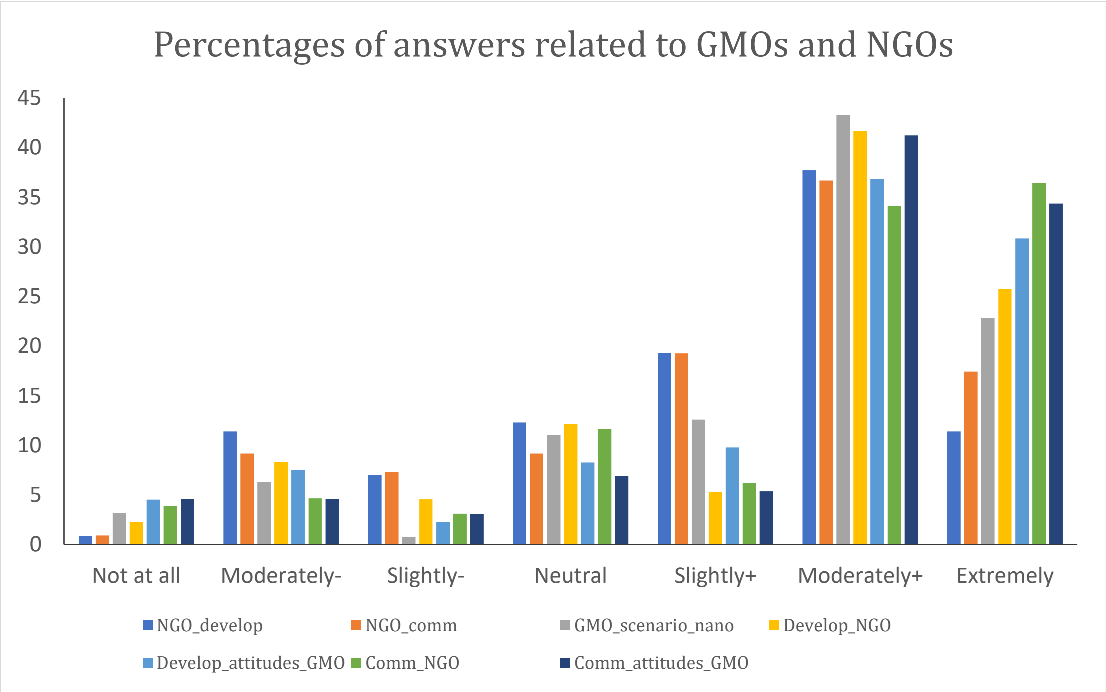
Figure 9 – Average response for each survey questions.

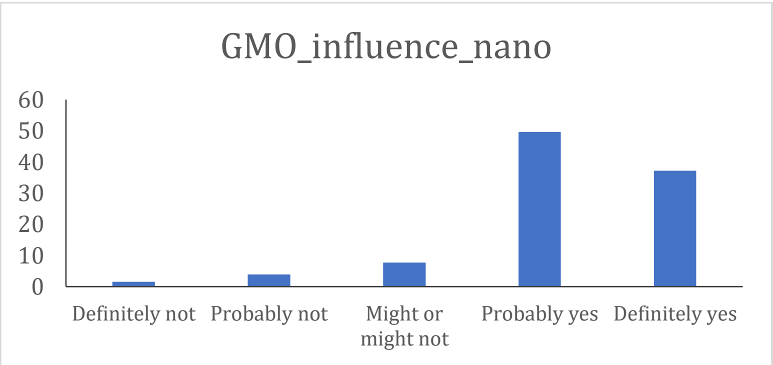


In the second section, *"Risk Assessment and Risk Management frameworks"*, respondents' opinions resulted to be quite homogeneous. The first question related to the flexibility of the regulations, the second to whether these regulations encourage the development and commercialization of nanotechnologies in agriculture. Noteworthy, these two questions have the lowest average response (2.01 and 3.46 for the first and second question, respectively, see Figure 9). In fact, particularly for the first question, 70.3% of respondents judged the RARM regulatory framework as strict or slightly strict (see Appendix III – Table 1d). Instead, while more than half of the sample (54.4%) believed that the RARM regulations do not encourage the development and commercialization of agro-nanotechnologies, the other 34% concluded otherwise. According to Wilcoxon signed-rank test, all these shifts of answers towards lower values than neutrality are significant ($P<0.001$ in both the cases, see Appendix III Table 2b). Thus, the test confirmed the second main hypothesis (i.e. the RARM frameworks are believed to constrain the development and commercialization of nanotechnologies in agriculture).

Another point that was investigated was also to what extent respondents think that NGOs campaigns and attitudes towards GMOs are influencing the development and commercialization of nanotechnologies in agriculture. Overall, respondents had rather similar opinions towards both NGOs and GMOs effects. This can be observed in Figure 10 below, where each bar corresponds to a different question that relate to NGOs or GMOs. These questions have some of the highest average response (see Appendix III, table 1d).

Figure 10 - Respondents' perceptions towards NGOs activities and GMOs inheritance.

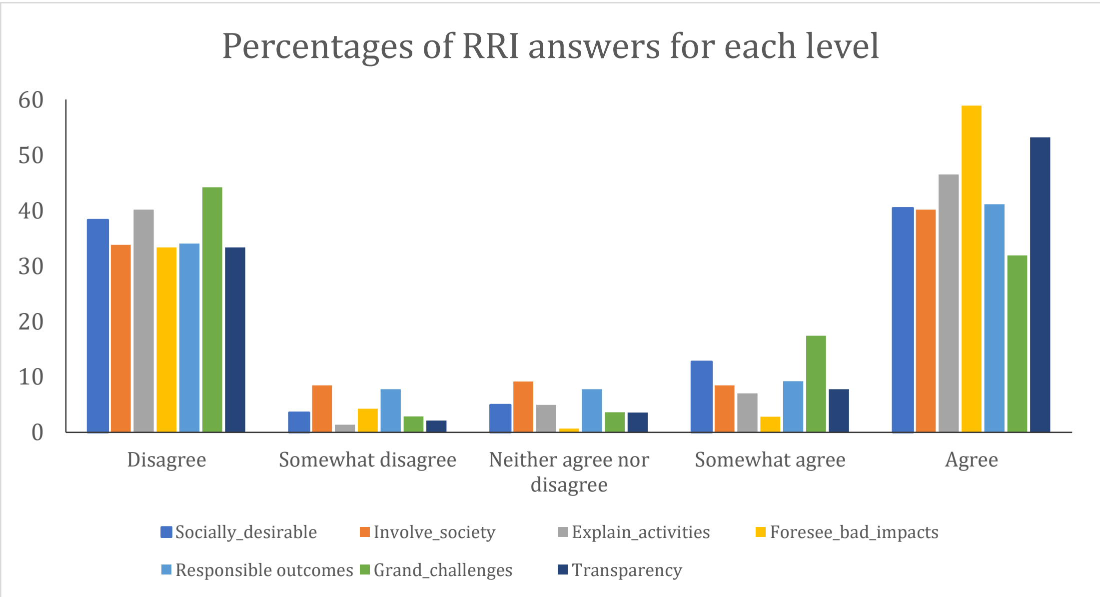




First, it is noteworthy that the 86.8% of respondents was pretty certain that the criticism about GM crops is likely to influence the development and commercialization of agro-nanotechnology. This question had the highest average response (4.17 on a 5-point Likert scale, see Figure 9). Second, NGOs activities and GMOs inheritance were perceived as primary causes that jeopardize and obstruct the development and commercialization of the technology (sample response rate ranges 68.4% to 80.9%). Wilcoxon signed-rank test showed that for all the questions related to NGOs and GMOs effects on nanotechnology commercialization and development, the distributions of the observations were always significantly shifted towards high values ($P<0.001$ in all the cases, see Appendix III Table 2c). This indicates that NGOs activity and GMOs inheritance are perceived to hamper the advancement of the technology. These findings relate to the answers given by the respondents in the third open question (*How is the critical approach described above able to influence the development and commercialization of agro-nanotechnologies?*). In fact, researchers and experts reported that the widespread criticism about GMOs is likely to influence nanotechnologies in agriculture through NGOs activities, lack of trust in science and public misinformation. To conclude, 62.3% of the respondents believed that their scientific freedom was reduced because of the European legislation of nanotechnologies.

In the fourth section, *"Responsible Research and Innovation framework"*, although 69.4% of the respondents considered the RRI process important for the development of the technology, respondents' opinions are strongly polarized in very positive and very negative values. This can be clearly observed in Figure 11 below, where each bar corresponds to a different RRI recommendation. This graph clearly shows the duality in respondents' ideas. While, on average, 53.9% of the sample agreed with the RRI guidelines, 46.1% disapproved them (see Appendix III – Table 1d). Wilcoxon signed rank test was performed on these variables. However, its results were not considered since, because of the polarization in opinions, the median of respondents' answers (which is used as test statistic) coincided with the hypothesized median in case of total neutrality of answers (i.e. *neither agree nor disagree*, which was the null-hypothesis). Therefore, the outcome of the test did not fit to the actual situation. Moreover, researchers and experts idea of what is a RRI process is in accordance with the definition set by the European Commission . Lastly, respondents reported that the RRI process is encouraged in their work environment by ethic committees, and through engaging stakeholders and collaborating with them to define what research process is relevant for the welfare of the society.

Figure 11 - Respondents' perceptions towards the recommendations to conduct a RRI process.



In the final section, respondents' opinions on to what extent the lack of communication between science and society, inadequate regulations and (Eco-)toxicological uncertainties may jeopardize the development of agro-nanotechnologies were similar. In fact, the respondents reported a positive connection between these factors and the impeding of both the development and commercialization of the technology (see Figure 9 and Appendix III – Table 1d). In particular, 57.3% and 64.7% of the respondents perceive inadequate regulations to hamper the development and commercialization of nanotechnologies, respectively. Moreover, these perceptions are exacerbated in relation to (eco-) toxicological uncertainties, with 65.9% and 70.6% of responses in relation to the development and commercialization of agro-nanotechnologies. In addition to this, the sample considered concerns of societal blockage as a main reason why the technology is not yet commercialized (20.7%). The other reasons (i.e. the technology is not developed yet, strict regulatory requirements, and the technology is not marketable) were chosen roughly evenly by the respondents (between 15.3% and 17.3%). High production costs and cultural differences between European countries were not perceived to have an impact on agro-nanotechnologies commercialization. Finally, most of respondents (55.4%) concluded that, if agro-nanotechnologies were commercialized, the divide between low-, middle-, and high-income countries would increase.

4.1.2 Multiple comparison tests

Mann-Whitney U, Kruskal-Wallis H and Dunn's tests

In order to assess whether the proportions of researchers and experts differed significantly between the categories within each socio-economic, demographic and background variable, a Mann-Whitney U Test (the non-parametric alternative to independent *t*-test) was performed (see Table 2). Distribution of gender and age of respondents differed significantly between researchers and experts. Concerning gender, an arbitrary value of 0 was assigned to "female" and a value of 1 to "male". Therefore, a higher mean rank indicate a higher number of males in the group considered. Since the mean rank was significantly higher in researchers than in experts ($P<0.05$), the test showed that there were significantly more males among researchers than among experts. With regard to age, each age class had a value from 1 to 6 (1 being the youngest age class, 6 being the oldest one). Therefore, the higher the mean rank, the older the respondents. The test showed that experts were significantly younger than researchers ($P<0.05$). Being a nonparametric test, no specific information can be given about the mean age of each group.

Table 2 - Researchers and experts' characteristics

Variable	Employment category		MW U value
	Researchers	Experts	
Gender	64.65	53.86	1395**
Age	65.36	52.67	1342**

Note: Mean ranks are reported.
** Significance level at 0.05

Then, another Mann-Whitney U Test was run to assess whether the answers given by respondents in each survey section differed significantly between researchers and experts (see Table 3). The answers to just three questions out of the 31 in total turned out to be significantly different between the two groups. In these three questions, values of answers ranged from 1 to 7 (being 1 not at all, being 7 extremely). Thus, also in this case it applies that the higher the mean rank, the higher the values that respondents gave to those questions. As reported in Table 4, the mean ranks were always higher for experts ($P<0.05$ in all the three cases). Hence, the test showed that experts think that inadequate regulations negatively affect both the development and the commercialization of nanotechnologies in a greater degree than researchers think. Moreover, the test also proved that experts believe that the lack of communication between science and society affect the commercialization of agro-nanotechnologies more than researchers do. As previously mentioned, being this a nonparametric test, no specific information can be given about the mean response of both researchers and experts with regard to each question. Globally, these results indicate that the test did not confirm the third main hypothesis (i.e. the recommendations to conduct a RRI process will be more supported by experts and more disapproved by researchers). In fact, no question specifically related to RRI process turned out to show significantly different answers between researchers and experts. However, the question about to what extent the lack of communication between science and society impedes the commercialization of agro-nanotechnologies relates to the recommendations to conduct a RRI process. In fact, RRI guidelines propose involvement of the public in the research and innovation process and explaining to them the research activities (which means favouring the communication between science and society). Therefore, the fact that both researchers and experts (particularly experts) think that this lack of communication impedes the advancement of nanotechnologies, reveal that respondents think that the scientific community should fill this communication gap.

Table 3 - Researchers and experts' responses.

Variable	Employment category		MW U value
	Researchers	Experts	
Develop_bad_regulations	41.19	59.66	678**
Comm_lack_communications	47.15	59.96	938**
Comm_bad_regulations	41.32	58.03	702**

Note: Mean ranks are reported.
** Significance level at 0.05

Kruskal-Wallis H tests were then performed to investigate whether level of background knowledge of respondents (i.e. knowledge on nanotechnology and familiarity with RARM and RRI frameworks, see Appendix IV, Table 1a) differed significantly across the different respondents characteristics (i.e. different socio-economic and demographic characteristics). Kruskal-Wallis (KW) H test was chosen because it is the non-parametric alternative to ANOVA. The test revealed just one statistical difference: *nano_knowledge* on *age*. Multiple comparisons (i.e. Dunn's test with Bonferroni correction[9]) was then performed to investigate among which age classes of respondents (i.e. 25-34, 35-44, 45-54, 55-64, >64) the level of nanotechnology knowledge (i.e. excellent, good, average, poor, terrible) differed significantly (see Table 4 and Appendix V, Figure 1). The test reported two statistical differences. In particular, the level of nano knowledge of respondents aged 35-44 years old is significantly lower than the level of nano knowledge of respondents between 55-64 and >64 years old ($P<0.001$ and $P<0.05$, respectively). Figure 1 in Appendix V shows the graphical representation of the results of the test, giving an indication of the actual distribution of the level of nano knowledge within each age class. From there, it can be observed that individuals whose age ranges between 35 and 44 years old have a level of nano knowledge that tends to be poor. Instead, respondents within 55-64 and >64 years old, have a nano knowledge that tends to be higher than the average.

Table 4 - Nanotechnology knowledge and respondents' age.

Sample1-Sample2	Test statistic	SE	Std. Test statistic	Sig.	Adj. Sig
55-64 - 35-44	32.75	9.63	3.4	0.001	0.007
> 64 - 35-44	27.91	11.64	2.4	0.017	0.165

Note: The significance level is 0.05. Adj. Sig is the significant values that have been adjusted by the Bonferroni correction for multiple tests.

[9] Bonferroni correction minimize the overall Type I error rate for the *m* multiple comparison tests, so that the error rate is less than or equal to the sum of the individual error rates for *m* tests (Ott & Longnecker, 2010).

Subsequently, the Mann-Whitney U test and Dunn's test with Bonferroni correction were run to understand whether the answers in each survey sections differed across the different levels of socio-economic, demographic and knowledge characteristics of respondents. The Mann-Whitney U Test was used for the background variables with just two levels (e.g. male and female for *gender*, complete results are in Table 5, 6 and 7), while the Dunn's test with Bonferroni correction was used for variables with more than two levels (e.g. excellent, good, average, poor and terrible for *nano_knowledge*, complete results are in Tables 8 to 12 and in Appendix V).

The first Mann-Whitney U test showed that distribution of the answers of just five questions turned out to be significantly different between males and females. In these five questions, values of answers ranged from 1 to 7 (being 1 *not at all*, being 7 *extremely*) (see Table 5). As in the previous cases, the higher the mean rank, the higher the values that respondents groups gave to those questions in each survey section. Since in the first question the mean rank was significantly higher in males than in females ($P<0.05$), the test showed that males believe significantly more than females that NGOs are successful in hampering the commercialization of nanotechnologies (mean ranks: 80.53 for males, 64.24 for females). With regard to the remaining four questions, the mean rank was always higher for females than for males ($P<0.05$). This indicates that females believe significantly more than males that both nanotechnologies (eco-)toxicological uncertainties and inadequate regulations impede the development and commercialization of agro-nanotechnologies. The test did not confirmed the first sub-hypothesis with regard to respondents gender (i.e. respondents who are male, young, not married and without children are more risk tolerant. This is translated into the expectation of more disapproving opinions towards both the risk assessment and risk management regulations and the recommendations to conduct a RRI process). In fact, no answer of survey questions specifically on RARM and RRI frameworks were found out to differ significantly among gender. However, females ascribe to the risks associated with nanotechnologies higher capacity in influencing the advancement of the technology, revealing attitudes of more risk aversion than males. It thus seems this study agree with the findings of Byrnes et al. (1999); Moerbeek and Casimir (2005) and Dohmen et al. (2011): women are more risk averse than men.

Table 5 - Respondents' gender and significant survey questions.

Variable	Gender		MW U value
	Female	Male	
NGO_comm	64.24	80.53	1795**
Develop_bad_regulations	85.48	68.94	1637**
Develop_uncertainty	92.60	66.29	1356**
Comm_bad_regulations	84.45	69.37	1682**
Comm_uncertainty	89.45	67.48	1482**

Note: Mean ranks are reported.
** Significance level at 0.05

The second Mann-Whitney U test showed that the distribution of answers turned out to be significantly different between parents and non-parents in just two questions. While in the first question values of answers ranged from 1 to 5 (being 1 *disagree* and 5 *agree*), in the second question values of answers ranged from 1 to 7 (being 1 *not at all*, being 7 *extremely*) (see Table 6). Surprisingly, the mean ranks of parents were significantly lower than the mean ranks of respondents with no children in both questions ($P<0.05$). Concerning the first question, this indicated that parents believe significantly less than non-parents that the researcher should involve the society in the development process of a nanotechnology. Instead, regarding the second question, the significantly lower mean rank of parents (69.18) indicated that they think more than non-parents (mean rank 83.85) that the eco-toxicological risks associated to nanotechnologies impede their commercialization in agriculture. Hence, the test did not confirm the first sub-hypothesis with regard of having children (i.e. *respondents* *who are male, young, not married and without children are more risk tolerant. This is translated into the expectation of more disapproving opinions towards both the risk assessment and risk management regulations and the recommendations to conduct a RRI process*). Furthermore, the findings in the studies of Dohmen et al. (2011) and Hanewald and Kluge (2014) are in contrast with those found in this study.

Table 6 – Having children and significant survey questions.

Variable	Children		MW U value
	No	Yes	
RRI_involve_society	86.97	71.49	1872**
Comm_uncertainty	83.85	69.18	1770**

Note: Mean ranks are reported.
** Significance level at 0.05

In the last test, it was shown that the distribution of the answers of only one question out of 31 in total turned out to be significantly different between Europeans and non-Europeans (see Table 7). The mean rank of non-Europeans is significantly higher than the mean rank of Europeans (P<0.005, mean ranks of 81.52 and 68.37, respectively). This indicates that respondents outside Europe believe significantly more than Europeans that the widespread criticism about GM crops will influence the development and commercialization of nanotechnologies in agriculture. Thus, the second sub-hypothesis was not confirmed (i.e *risk assessment and risk management regulations, as well as responsible research and innovation recommendations are differently assessed depending on geographical region and employment type*). In fact, no answer on RARM regulations and RRI recommendations was found out to be significantly different among respondents from different geographical regions (here relating to continents).

Table 7 – Europeans and non-Europeans and significant survey questions.

Variable	Country_membership		MW U value
	Not European	European	
GMO_influence_nano	81.52	68.37	2080**

Note: Mean ranks are reported.
** Significance level at 0.05

As mentioned before, *Age, Employment, Nano_knowledge, RARM_familiar and RRI_familiar* are not binary variables and were thus analysed with five Dunn's tests.

The first test (see Table 8 and Appendix V Figure 2) showed that the distribution of answers of only one question turned out to differ significantly between respondents belonging to different age classes. In particular, respondents between 25-34 years old believe significantly more than those between 45-54 years old that the development of nanotechnologies in agriculture has changed in practice after the introduction of the recommendations to conduct a RRI process (P<0.05). Thus, the test did not confirm the first sub-hypothesis with regard to respondents' age (i.e. *respondents who are male, young, not married and without children are more risk tolerant. This is translated into the expectation of more disapproving opinions towards both the risk assessment and risk management regulations and the recommendations to conduct a RRI process*).

Table 8 - Respondents' age and significant survey questions.

Test field	Sample1-Sample2	Test statistic	SE	Std. Test statistic	Sig.	Adj. Sig
RRI_change_practice						
	25-34 - 45-54	29.98	10.76	2.79	0.005	0.053

Note: The significance level is 0.05. Adj. Sig is the significant values that have been adjusted by the Bonferroni correction for multiple tests.

The second Dunn's test displayed that the distribution of answers of four questions resulted to be significantly different across the different employment groups of respondents. Concerning the first two questions, private researchers think significantly more than public researchers that NGOs are successful in undermining both the development and commercialization of nanotechnologies in agriculture (P<0.001 in both cases). Furthermore, also private experts believe significantly more than public researchers that NGOs are successful in undermining nanotechnologies commercialization (P<0.05). With regard to the last two questions, both private and public experts think significantly more than private and public researchers that inadequate regulations impede the development and commercialization of agro-nanotechnologies (P<0.001 in all cases, except *PuRe – PrEm,* for which P<0.05. See Table 9 below and Appendix V Figure 3). This test did not confirm the second sub-hypothesis with regard to respondents employment type (i.e. *risk assessment and risk management regulations, as well as responsible research and innovation recommendations are differently assessed depending on geographical region and employment type*). In fact, answers of any question about RARM regulation and RRI recommendations did never differ significantly among respondents with different occupations.

Table 9 - Respondents' employment type and significant survey questions.

Test field	Sample1-Sample2	Test statistic	SE	Std. Test statistic	Sig.	Adj. Sig
NGO_develop						
	PuRe - PrRe	-21.65	7.64	-2.83	0.005	0.028
NGO_comm						
	PuRe - PrEm	-14.29	6.91	-2.07	0.039	0.232
	PuRe - PrRe	-19.39	7.56	-2.57	0.01	0.062
Develop_bad_regulations						
	PrRe - PuEm	-24.83	9.39	-2.64	0.008	0.049
	PrRe - PrEm	-28.15	9.39	-3	0.003	0.016
	PuRe - PrEm	-17.33	7.49	-2.13	0.021	0.124
Comm_bad_regulations						
	PrRe - PrEm	-27.13	9.16	-2.96	0.003	0.018
	PrRe - PuEm	-29.03	9.38	-3.1	0.002	0.012

Note: The significance level is 0.05. Adj. Sig is the significant values that have been adjusted by the Bonferroni correction for multiple tests. PuRe = Public Researcher; PrRe = Private Researcher; PuEm = Public Employee; PrEm = Private Employee.

The third Dunn's test reported that the distribution of answers of only one question resulted significantly different across groups of respondents with different levels of nano knowledge. In particular, as it is graphically shown in Appendix V – Figure 5, respondents whose level of nano knowledge is good believe significantly more than those whose nano knowledge was excellent, poor and terrible, that researchers should develop a nanotechnology that is socially desirable (i.e. benefit all without discrimination) (P<0.05 in all cases, except *T-G* for which P<0.001). Additionally, respondents with an average nano knowledge think significantly more than individuals with a terrible nano knowledge that the nanotechnologies developed by researchers should be socially desirable (P<0.05). Hence, the test partially confirmed the third sub-hypothesis (i.e. *respondents' opinions on risk assessment and risk management regulatory frameworks and on recommendations to conduct a responsible research and innovation process are different depending on individuals' knowledge on nanotechnologies and on their familiarity with RARM and RRI frameworks*). In fact, despite respondents' opinions on RRI process were found to differ significantly according to the nano knowledge level in one question related to RRI recommendation, such differences were never found in the questions related to RARM regulations.

Table 10 - Respondents' expertise and significant survey questions.

Test field	Sample1-Sample2	Test statistic	SE	Std. Test statistic	Sig.	Adj. Sig
RRI_socially_desirable						
	T - A	45.39	19.76	2.3	0.022	0.216
	T - G	58.34	20.31	2.87	0.004	0.041
	E - G	-34.01	14.47	-2.35	0.019	0.188
	P - G	10.56	9.2	2.24	0.025	0.254

Note: The significance level is 0.05. Adj. Sig is the significant values that have been adjusted by the Bonferroni correction for multiple tests. T = Terrible; P = Poor; A = Average; G = Good; E = Excellent.

Finally, the last Dunn's test reported that the distribution of answers of four questions differed significantly between respondents with different RARM familiarity (see Table 11 and Appendix V Table 6). In particular, with regard to the first two questions, respondents who are not familiar at all with the RARM regulations believe significantly less than individuals whose familiarity is moderate, high and extreme that NGOs activities and attitudes towards GMOs obstruct the development of nanotechnologies in agriculture ($P<0.05$). Regarding this latter aspects, $P<0.001$ between respondents that are not familiar at all and those that are very familiar with RARM. In addition to this, in the first question respondents that are moderately familiar with the RARM regulations think significantly less than respondents with high and extreme familiarity that NGOs hamper the development of agro-nanotechnologies ($P<0.05$). Concerning the last two questions, individuals with a high familiarity with RARM regulations think more than respondents that are moderately familiar that NGOs activities and attitudes towards GMOs impede the development and commercialization of agro-nanotechnologies ($P<0.001$). Moreover, those who are very familiar with RARM regulations think more than individuals with a moderate, low and no familiarity that the commercialization of nanotechnologies is blocked by attitudes towards GMOs. Thus, the Dunn's test did not confirm the third sub-hypothesis with regard to respondents RARM familiarity (i.e. *respondents' opinions on risk assessment and risk management regulatory frameworks and on recommendations to conduct a responsible research and innovation process are different depending on individuals' knowledge on nanotechnologies and on their familiarity with RARM and RRI frameworks*). Finally, the test did not confirm the third sub-hypothesis with regard to respondents RRI familiarity as answers to none of the questions was found to differ significantly between respondents with different RRI familiarity.

Table 11 - Respondents' RARM familiarity and significant survey questions.

Test field	Sample1-Sample2	Test statistic	SE	Std. Test statistic	Sig.	Adj. Sig
Develop_NGO						
	NF - SF	24.45	11.35	2.15	0.031	0.313
	NF - VF	31	11.35	2.73	0.006	0.063
	NF - EF	41.84	14.69	2.85	0.004	0.044
	MF - VF	20.02	8.57	2.34	0.02	0.195
	MF - EF	30.87	12.67	2.44	0.015	0.148
Develop_attitudes_GMO						
	NF - MF	20.63	10.43	1.98	0.048	0.479
	NF - EF	32.4	14.72	2.2	0.028	0.277
	NF - VF	35.29	11.28	3.13	0.002	0.018
Comm_NGO						
	MF - VF	25.21	8.42	2.99	0.003	0.028
Comm_attitudes_GMO						
	NF - EF	28.38	14.43	1.97	0.049	0.491
	NF - VF	42.2	11.15	3.79	0	0.002
	MF - VF	23.13	8.42	2.75	0.006	0.06
	SF - VF	22.13	9.48	2.33	0.02	0.196

Note: The significance level is 0.05. Adj. Sig is the significant values that have been adjusted by the Bonferroni correction for multiple tests. PuRe = Public Researcher; PrRe = Private Researcher; PuEm = Public Employee; PrEm = Private Employee.

Following University of Minnesota (2016) *"World Regional Geography: People, Places and Globalization"*, European countries were grouped into 5 different regions to investigate whether the distribution of answers to the questions in each survey sections were significantly different between respondents from different European regions (i.e. Western Europe (WE), Eastern Europe (EE), Northern Europe (NE), British Isles (BI) and Southern Europe (SE)). As before, the Dunn's test was performed (see Table 11 and Appendix V – Figure 4). The test shows that the distribution of answers of three survey questions differed significantly between respondents from different European regions. Concerning the first question, Southern Europeans believe significantly more than Western and Eastern Europeans as well as than British respondents that researchers should develop an agro-nanotechnology that is socially desirable ($P<0.001$ in all cases, except for *EE-SE* with $P<0.05$). With regard to the second question, respondents form British Isles and Eastern Europeans think significantly less than Southern, Northern and Western Europeans that researchers should involve the society in the research and innovation process of agro-nanotechnologies ($P<0.05$,except for EE-SE and BI-SE with $P<0.001$). Finally, the Dunn's test showed that both Northern and Eastern Europeans believe significantly less than Western Europeans and Respondents from British Isles that a divide between low-, middle-, and high-income countries is likely to occur after the introduction of nanotechnologies in agriculture ($P<0.05$). In addition, Southern Europeans think significantly more than Eastern Europeans that the latter divide is likely to occur ($P<0.05$). Thus, the second sub-hypothesis is partially confirmed (i.e. *risk assessment and risk management regulations, as well as responsible research and innovation recommendations are differently assessed depending on geographical region and employment type*). In fact, answers to none of the questions related to RARM regulations were found to be significantly different between respondents from different geographical regions (here intended as European regions). Furthermore, results of this test contrast with those in the Eurobarometer (2010) study, where Northern Europeans were found to believe more than southern and eastern Europeans and respondents from British Isles that nanotechnologies do not help people in developing countries.

Table 12 – Respondents' geographical position and significant survey questions.

Test field	Sample1-Sample2	Test statistic	SE	Std. Test statistic	Sig.	Adj. Sig
RRI_socially_desirable						
	BI - SE	-32.93	9.03	-3.65	0	0.003
	WE - SE	-28.49	6.42	-4.44	0	0
	EE - SE	-24.48	12.03	-2.04	0.041	0.41
RRI_involve_society						
	WE -EE	23.89	11.39	2.1	0.036	0.359
	WE -BI	16.92	8.1	2.09	0.037	0.368
	EE - SE	-34.83	12.12	-2.87	0.004	0.041
	EE - NE	-37.9	15.33	-2.47	0.013	0.134
	BI - SE	-27.85	9.1	-3.06	0.002	0.022
	NE - BI	30.93	13.07	2.36	0.018	0.18
Nano_divide						
	NE - SE	-23.05	11.43	-2.02	0.044	0.437
	NE - BI	-31.12	12.4	-2.51	0.012	0.121
	WE - NE	24.9	10.78	2.31	0.021	0.209
	WE - EE	19.32	9.46	2.04	0.041	0.411
	EE - BI	-25.54	11.26	-2.27	0.023	0.233

Note: The significance level is 0.05. Adj. Sig is the significant values that have been adjusted by the Bonferroni correction for multiple tests. NE = Northern Europe; WE = Western Europe; EE = Eastern Europe; SE = Southern Europe; BI = British Isles.

4.2 Factor analysis

Having determined the number of factors to retain from the parallel analysis (see Table 3), a factor analysis was computed. From the variables included in each factor and from the value of the loadings (i.e. values that represent the correlations between the latent common factors and the variables in the data set), a name was chosen. With factor analysis, the latent constructs uncovered, represents indicators of respondents' perceptions. On the one hand, the first factor – *General_blockage* – captured individuals' perceptions in relation to how several factors (NGOs, GMOs, inadequate regulations and nanotechnologies (eco-)toxicological uncertainties) impede both the development and commercialization of agro-nanotechnologies. On the other hand, the third factor – *Foreign_blockage* – specifically reflects respondents' opinions on the role of NGOs activities and GMOs inheritance in hampering the advancement of nanotechnologies. Furthermore, while the second factor – *Fundamentals* – grasped opinions towards the European legislation, the fourth – *RRI_expectations* – reflected individuals' perceptions explicitly on the recommendations to conduct a responsible research and innovation process.

Successively, a reliability statistic was performed to measure the internal consistency of each factor (i.e. Cronbach's alpha coefficients - α) (see Table 12). It measures whether the items (i.e. variables included in each factor) – that propose to measure the same general construct – produce similar scores (Armor, 1973; Tavakol & Dennick, 2011). Cronbach's alpha coefficients indicated a high level of internal consistency ($\alpha > 0.7$), suggesting that the items in each factor are producing similar scores.

Table 13 - Reliability statistics of factors internal consistency.

Factor solution	# Items	Eigenvalue	Cronbach's Alpha
1	15	10.894	0.924
2	10	2.211	0.831
3	5	1.898	0.786
4	7	2.044	0.797

To classify respondents based on their perceptions, the factor scores saved from the analysis were employed. Thus, a Mann-Whitney U test was computed to compare the perceptions among researchers and experts (see Appendix VI). In accordance with the outcome of the multiple comparison test reported in Table 4, one statistical difference was reported, *Employment_categories* on the factor *General_blockage*.

4.3 Cluster Analysis

As reported in paragraph 3.4.2, five clusters were retained as the observation per cluster were more even than in the two-cluster solution (Table 13). To label each group, sample and cluster means were calculated, as shown in Table 14.

Table 14 - Cluster name and percentages of observation for each cluster.

Cluster solutions	Percentages
Confidence in the development and commercialization of agro-nanotechnologies (CDC)	12 (18)
GMOs and NGOs barrier (GNB)	26 (38)
Legislation skepticism (LS)	17 (24)
Definition acceptance (DA)	20 (29)
RRI dualism (RRID)	25 (37)

Note: number of observations are in parentheses.

Table 15 – Cluster means for survey statements and questions.

No.	Survey question	Cluster					Full sample
		CDC	GNB	LS	DA	RRID	
1	The definition of nanotechnology adopted in the European legislation is:	0.83	2.89	1.67	4.00	3.92	2.92
2	To what extent is the European definition of nanotechnology laying the foundations for a regulatory framework capable of incentivizing the development of nanotechnologies in agriculture?	0.00	2.21	1.38	4.86	4.73	2.97
3	To what extent is the European definition of nanotechnology laying the foundations for a regulatory framework capable of incentivizing the commercialization of nanotechnologies in agriculture?	0.00	1.76	1.46	4.86	4.62	2.84
4	In order to be able to commercialize agro-nanotechnologies, the European risk assessment and risk management regulatory frameworks is:	0.72	1.21	0.96	1.69	1.92	1.38
5	To what extent does the European legislation (Risk Assessment, Risk management frameworks) encourage the development and commercialization of nanotechnologies in agriculture?	0.33	1.87	0.79	3.76	3.78	2.36
6	To what extent are NGOs anti-nano campaigns successful in undermining the development of nanotechnologies in agriculture?	0.61	6.03	0.58	4.97	4.24	3.80
7	To what extent are NGOs regulatory requests about safety measures successful in slowing down the commercialization process of nanotechnologies in agriculture?	0.67	5.87	0.46	5.07	4.22	3.76
8	To what extent is a Responsible Research and Innovation (RRI) fundamental in the development process of nanotechnologies in agriculture?	1.39	3.89	3.08	5.31	5.43	4.12
9	The researcher should develop a nanotechnology that is socially desirable	1.72	3.32	2.42	2.07	4.27	2.97
10	The researcher should involve the society in the research process	1.94	3.11	2.83	2.66	3.54	2.94
11	The researcher should comprehensively explain its activities to the public	2.06	3.42	3.21	2.28	3.49	3.01
12	The researcher should foresee unintended impact(s) of the nanotechnology	1.89	3.50	3.88	1.62	4.78	3.32
13	The researcher should be held responsible of the outcomes (positive or negative) of the nanotechnology	1.50	3.37	2.67	2.00	4.30	2.99
14	The researcher should develop a nanotechnology that will solve "grand challenges" (e.g. resource depletion)	1.28	3.26	3.04	2.17	3.03	2.71
15	The researcher should be transparent (share knowledge, no information asymmetries)	1.83	3.26	3.38	2.59	4.16	3.20
16	In your work environment, to what extent is to conduct a Responsible Research and Innovation (RRI) process encouraged?	1.17	2.97	3.17	4.00	4.70	3.42
17	After the European recommendation for conducting a RRI process, the development of nanotechnologies in agriculture has changed in practice.	0.00	1.37	0.88	2.59	2.51	1.65
18	Europe is characterized by a widespread criticism about GM crops. Do you think this critical approach is influencing the development and commercialization of nanotechnologies in agriculture?	1.72	4.71	3.04	3.62	4.05	3.68
19	To what extent is the blockage of GM crops possible to occur to nanotechnology applications in agriculture?	0.89	6.03	4.54	5.34	4.95	4.74
20	Lack of communication between science and society impedes the development of agro-nanotechnologies.	0.61	4.63	5.38	5.66	5.32	4.64
21	Inadequate regulations impede the development of agro-nanotechnologies.	0.44	3.71	4.21	4.97	4.35	3.80
22	NGOs campaigns impede the development of agro-nanotechnologies.	0.72	6.37	4.83	5.31	5.00	4.86
23	Nanotechnology (eco-)toxicological uncertainties impede the development of agro-nanotechnologies.	0.11	4.32	4.63	5.45	4.73	4.18
24	Attitudes towards GMOs impede the development of agro-nanotechnologies.	0.89	6.18	5.00	5.38	5.35	4.97
25	Lack of communication between science and society impedes the commercialization of agro-nanotechnologies.	0.72	5.08	5.63	5.79	5.68	4.92
26	Inadequate regulations impede the commercialization of agro-nanotechnologies.	0.11	3.89	4.79	5.28	4.81	4.08
27	NGOs campaigns impede the commercialization of agro-nanotechnologies.	0.06	6.47	5.42	5.38	5.11	4.95
28	Nanotechnology (eco-)toxicological uncertainties impede the commercialization of agro-nanotechnologies.	0.44	4.82	5.25	5.55	4.43	4.40
29	Attitudes towards GMOs impede the commercialization of agro-nanotechnologies.	0.39	6.53	5.46	5.31	5.41	5.07
30	Agro-nanotechnologies are not commercialized because the technology is not developed yet.	0.50	2.66	2.75	3.72	3.41	2.81
31	Agro-nanotechnologies are not commercialized because of the strict regulatory requirements for their approval.	0.00	0.32	0.42	0.38	0.32	0.31
32	Agro-nanotechnologies are not commercialized because of the concerns of societal blockage.	0.00	0.50	0.25	0.41	0.27	0.32
33	Agro-nanotechnologies are not commercialized because the technology is not marketable yet.	0.06	0.55	0.33	0.48	0.46	0.42
34	Agro-nanotechnologies are not commercialized because of high production costs.	0.06	0.45	0.33	0.48	0.30	0.35
35	Agro-nanotechnologies are not commercialized because of cultural differences between European countries.	0.00	0.18	0.21	0.31	0.24	0.21
36	Not sure about why agro-nanotechnologies are not commercialized.	0.00	0.13	0.17	0.14	0.24	0.15
37	If agro-nanotechnologies are commercialized, it is likely that the divide between low-, middle-, and high-income countries will:	0.89	0.13	0.33	0.14	0.16	0.27

Note: CDC = Confidence in the development and commercialization of agro-nanotechnologies; GNB = GMOs and NGOs barriers; LS = Legislation skepticism; DA = Definition acceptance; RRID = RRI dualism. The mean scores reported in grey are the cells for which specific characteristics apply to respondents and from where the cluster name was chosen.

By looking at the differences between cluster means, the first cluster reported low values for statements that expressed concerns over certain facets that may hamper the development and commercialization of agro-nanotechnologies (statements from 20 to 29 and 37). Thus, a certain level of confidence was revealed. The cluster was thus named *"Confidence in the development and commercialization of agro-nanotechnologies (CDC)"*. The second cluster had the highest values for statements 6, 7, 18, 19, 22, 24, 27, 29 and 32. These represented questions related to what extent GMOs and NGOs block the development and commercialization of agro-nanotechnologies. Thus, it was called "*GMOs and NGOs barrier (GNB)"*. The third cluster was labelled *"Legislation skepticism (LS)"* because statements 1, 2, 3, 4, 5, 21, 22, 26 and 27 had high values. These, referred to the magnitude of European legislation in curbing the development and commercialization of agro-nanotechnologies. Conversely, in cluster number four statements 1,2 and 3 displayed high values for nanotechnology definition acceptance. It was then named *"Definition Acceptance (DA)"*. Finally, cluster five reported high values for statements on the RRI process and how the researcher should behave in the innovation process (statements from 8 to 16). However, as seen in the previous chapter respondents' perceptions are polarized. From this, followed its label – *"RRI dualism (RRID)"*.
Considering the above-reported discussion on respondents' beliefs, it can be concluded that these clusters successfully group together the researchers and experts' perceptions analysed and discussed until now.

A Kruskal-Wallis H test (see Table 15) was performed to test if the factor scores differed, on average, across the five-cluster solution.

Table 16 - Respondents' perceptions identified through cluster analysis.

Factor solution	Cluster					χ^2-statistic
	CDC	GNB	LS	DA	RRID	
General blockage	-2.12 (0.47)	0.18 (0.58)	0.51 (0.55)	0.45 (0.62)	0.16 (0.81)	50.306**
Fundamentals	-1.30 (0.28)	-0.45 (0.59)	-0.90 (0.83)	0.95 (0.46)	0.94 (0.53)	105.362**
Foreign blockage	-1.22 (1.41)	0.27 (0.75)	0.09 (1.08)	-0.84 (0.76)	0.92 (0.44)	69.828**
RRI expectations	1.31 (0.65)	-1.17 (0.47)	1.10 (0.55)	-0.21 (0.67)	0.02 (0.64)	103.982**

Note: CDC = Confidence in the development and commercialization of agro-nanotechnologies; GNB = GMOs and NGOs barriers; LS = Legislation skepticism; DA = Definition acceptance; RRID = RRI dualism.
** Significance at 0.05 level.

The test convey that there was significant intra-cluster homogeneity and inter-cluster heterogeneity (i.e. the distance from the mean of each group to the overall mean is large (Kim, 2017)). For example, by looking at Table 15, it can be seen that those respondents that were confident in the development and commercialization of nanotechnologies in agriculture (CDC) had negative values for *general blockage, fundamentals and foreign blockage*. Thus, these values indicated that they did not perceive those factors as worrying.
Subsequently, to compare the means of the five cluster solutions with respondents' background information[10] a Kruskal-Wallis H test was performed (see Appendix VII). It reported that five sample's characteristics influenced respondents' perceptions towards agro-nanotechnologies progress – age, European region of origin, knowledge on nanotechnologies, familiarity with RARM and RRI.
Consequently, a multiple comparisons test (i.e. Dunn's test with Bonferroni correction) was computed (see Table 16 and Appendix VIII for graphical representation). Several facets are noteworthy. First, the group with respondents that found acceptable the definition of nanotechnology was composed, on average, by older individuals compared to other clusters. Second, in the cluster of those individuals who were both

[10] Gender, age, marital status, children, country membership, European countries, European regions, employment, employment categories, nano knowledge, RARM and RRI familiarity.

skeptical towards European legislation and confident in the advancement of nanotechnologies, the knowledge on nanotechnologies was, on average, higher than respondents knowledge in the other clusters. Finally, in the groups characterised by both legislation skepticism and confidence in the development and commercialization of nanotechnologies, respondents had, on average, higher familiarity with the risk assessment and risk management regulatory framework, and with the recommendations to conduct a responsible research and innovation process.

Table 17 - Sample's characteristics and their influence on respondents' perceptions.

Test field	Sample1-Sample2	Test statistic	SE	Std. Test statistic	Sig.	Adj. Sig
Age						
	DA - LS	-32.44	11.29	-2.87	0.004	0.041
	DA - CDC	-32.23	12.28	-2.63	0.009	0.087
	DA - RRID	21-94	10.15	2.16	0.031	0.306
European_regions						
	DA - RRID	-18.85	7.40	-2.55	0.011	0.109
	DA - GNB	19.92	7.47	2.67	0.008	0.077
	DA - CDC	23.90	9.00	2.66	0.008	0.079
Nano_knowledge						
	DA - LS	41.92	11.06	3.79	0.000	0.002
	DA - CDC	47.84	12.03	3.98	0.000	0.001
	RRID - LS	34.79	10.51	3.31	0.001	0.009
	RRID - CDC	40.71	11.52	3.53	0.000	0.004
	GNB - LS	-28.54	10.45	-2.72	0.006	0.064
	GNB - CDC					
RARM_familiar						
	DA - LS	31.04	11.30	2.75	0.006	0.060
	DA - CDC	42.18	12.82	3.43	0.001	0.006
	GNB - RRID	-18.99	9.45	-2.01	0.045	0.445
	GNB - LS	-100.00	10.67	-3.80	0.000	0.001
	GNB - CDC	51.74	11.71	4.42	0.000	0.000
	RRID - LS	21.60	10.73	2.01	0.044	0.440
	RRID - CDC	32.74	11.76	2.78	0.005	0.054
RRI_familiar						
	DA - LS	45.52	11.13	4.10	0.000	0.000
	DA - CDC	63.06	12.10	5.12	0.000	0.000
	GNB - LS	-27.13	10.51	-2.59	0.010	0.097
	GNB - CDC	44.72	11.54	3.88	0.000	0.001
	RRID - LS	28.97	10.57	2.74	0.006	0.061
	RRID - CDC	46.51	11.59	4.01	0.000	0.001

Note: The significance level is 0.05. Adj. Sig is the significant values that have been adjusted by the Bonferroni correction for multiple tests. CDC = Confidence in the development and commercialization of agro-nanotechnologies; GNB = GMOs and NGOs barriers; LS = Legislation skepticism; DA = Definition acceptance; RRID = RRI dualism.

Chapter 5 – Discussion

5.1 Nanotechnology definition and RARM regulatory frameworks and their implication in European agricultural legislation

As pointed out in the second chapter, the need of a new definition of nanotechnologies is widely recognized (Calabia et al., 2010; Kah & Hofmann, 2014; Mueller et al., 2012; Parisi et al., 2014; Parisi et al., 2015; Rauscher et al., 2017; Salvi, 2015; Semo et al., 2007). However, surprisingly and unexpectedly, the definition of nanotechnology was significantly accepted among researchers and experts. Parisi et al. (2014) assert that companies are facing some difficulties as the definition cover also those nanomaterials that are already in the market and were not manufactured on purpose (e.g. clay, silica). This challenges are intensified by the fact that companies want to avoid GMOs inheritance. However, under the REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulations, although the term substances cover nanomaterials, these are not specifically mentioned. Furthermore, under the REACH, a substance requires the registration only if it is commercialized in a volume that exceed 100 tonnes. Giving all these arguments, with regard to nanotechnologies in agriculture, future studies are needed to investigate what factors that influence researchers and experts' perception on the acceptance of the nanotechnologies definition are (i.e. fundamental research, regulatory uncertainties under the REACH). Furthermore, as nanotechnologies have a wide range of applications, future research may assess whether researchers and experts from different sectors perceive the definition of nanotechnologies in different ways.

What is another remarkable outcome from this study, is that the *ad hoc* risk assessment and risk management regulatory framework are considered to be significantly strict from the respondents. Furthermore, researchers and experts also significantly believe that RARM regulations do not encourage on the development and commercialization of nanotechnologies. As pointed out in paragraph 2.3, at the European level, depending on in which sector nanotechnologies are use, several are the European agencies that deals with their risk assessment (i.e. SCHENIR, SCCS, EFSA, EMA) (European Commission, 2012a). The ECHA (European Chemical Agency) has the specific role of assessing the risk and composition of chemical substances, and a specific risk assessment scheme applies to nanotechnologies (see Figure2). This scheme for the risk assessment of nanomaterials does not differ substantially from the risk assessment for other substances. However, as nanomaterials have a size range of 1-100 nm, when the size of one or more compound in the nanoform is modified the risk assessment has to be undertaken again. In fact, *"the safety assessment of substances* (which term covers nanomaterials) *must be done on a case-by-case basis."* (European Commission, 2016). Moreover, as showed by Choi et al. (2009) the risk assessment for nano-compounds is far more costly than for other compounds, depending on "*the degree to which a nanomaterial is considered "safe" or "hazardous" has a direct effect on the level of testing."*.

Hansen (2017) is the first that tried to provide a model for a unified legislation for nanomaterials. He called it REACT NOW (Registration, Evaluation, Authorization, Categorization and Tools to Evaluate Nanomaterials – Opportunities and Weaknesses), and it is based on the definition of nanomaterials suggested by the SCHENIR as it would cover those nanomaterials that are not currently comprised in the European definition. It states that *"a material is considered to be a nanomaterial when >0.15% of the particle size distribution is <100 nm or, for dry materials, when the volume-specific surface area is >60 m^2 cm^{-3}[...]"*

(Hansen, 2017). Furthermore, the registration and evaluation of nanomaterials has to be pursued only if the technology wants to be commercialized and after the registrant have explained the functional use and effectiveness of the nanotechnology. In doing so, a colour code will be assigned to the corresponding environmental and health hazards. Hence, this proposal for a unified regulatory framework represent propose itself as a starting point for future nanotechnology regulations that allow, on the one hand, flexibility, and on the other hand ensure "*safety prior to use*" (Hansen, 2017). Lastly, to reduce the tremendous costs deriving from assessing the risks of nanotechnology, the Dutch National Institute for Public Health and the Environment (RIVM) published a report that provide a strategy towards grouping nanomaterials (Seller et al., 2015). Through the characterization of nanomaterials (i.e. chemical identity, particle characterization, transport behaviour, activity and reactivity), it is possible to identify materials to use as a reference for testing and grouping "new" nanomaterials. Hence, the researcher formulate hypothesis on whether and how a nanomaterial exhibit or not a unique behaviour from the reference material. Then laboratory test are needed to collect data. These tests might occur in three tiers, depending on the available information on possible hazards of the nanomaterials. After Tier 2, it is possible to group nanomaterials that have similar behaviour. However, this depend on available data. Thus, although it is a positive starting point for reducing risk assessment costs, more research is needed to increase physical-chemical properties of nanomaterials to create a broader and comprehensive framework to group nanomaterials.

Given all the arguments and findings above, it seems interesting for future research assessing whether researchers and experts perceive that a standardization of the regulatory framework for nanomaterials, for example the REACT NOW, would encourage the development and commercialization of nanotechnologies more than the actual regulatory framework. In addition to this, future research could also focus on whether this standardization would be perceived as more flexible. Lastly, future studies could investigate, through a cost analysis, to what extent the strategy proposed by the RIVM would quantitatively reduce the costs compared to the current risk assessment procedure.

5.2 Responsible Research and Innovation process – Implications for the development and commercialization stages

Despite some background information[11] were significant in influencing respondents' perceptions towards the recommendations to conduct a RRI process, overall researchers and experts' judgments were strongly polarized. This can be clearly observed in Figure 9. The objections raise in Paragraph 2.4 indicate a reason for this dualism in opinions. However, respondents believe that the lack of communication between science and society is major cause in impeding the development and commercialization of agro-nanotechnology, 70.3% and 70.6% respectively. Furthermore, respondents between 25-34 years old believe significantly more than those between 45-54 years old that the development of nanotechnologies in agriculture has changed in practice after the introduction of the recommendations to conduct a RRI process. In this regard, important is the concept of lock-ins. In literature, a lock-ins is defined as the increasingly difficult deviation from the initial path, and thus can lead to path-dependency (Klitkou et al., 2015; Knill & Tosun, 2012). Lock-ins have a particular impact on institutions, where "*formal constraints, such as legislation, economic rules and contracts, and informal constraints, such as social conventions and codes of behaviour*" shape individuals behaviour (Foxon, 2018). Future research may focus on

[11] Age, Children, Nano_knowledge and European_regions.

understanding how to conciliate researchers and experts opinion on the recommendations to conduct a RRI process, and on investigating whether informal constraints challenge the implementation of these guidelines.

The Eurobarometer (2010) report that in Europe just a small part of the society is aware of nanotechnologies and these do not have develop a point of view yet. Furthermore, as stated in Paragraph 2.4, although researchers acknowledge that a lack of communication with the society is a major aspect that impedes the advancement of nanotechnologies in agriculture, scientists are concerned that the public will misunderstand any communication attempt (Besley & Nisbet, 2013). This is also a reason why researchers and experts are concerned of societal blockage (Gupta et al., 2015; Jones, 2008). In these regard, given the late advancements in medicine in cancer treatment (Bertrand et al., 2014; Ferrari, 2005), nanotechnologies could be introduced as beneficial for the society. Thus, future studies may focus on investigating whether researchers and experts concerns have real basis, and whether and how these worries affect both the development and commercialization stage of nanotechnologies in agriculture. Furthermore, it could be inspected whether sowing the seed of improved health care derived from the introduction of nanotechnologies in medicine would favour the introduction of nanotechnologies in agriculture.

Finally, although the dimension of responsiveness implies that all stakeholders are mutually responsible, in the Code of Conduct for Responsible N&N is specifically tailored to researchers. In addition to this, the 62.3% of respondents perceive their scientific freedom to be reduced after the European legislation towards nanotechnologies. Thus, these arguments should be taken into consideration by policy makers in developing further recommendations and/or regulations.

To conclude, other two interesting and unexpected outcomes arose from this study. First, in contrast with the findings of Dohmen et al. (2011) and Hanewald and Kluge (2014), this study revealed that respondents without children have more risk averse attitudes than parents. However, the studies above mentioned do not specifically relate to nanotechnologies. Second, in contrast with the findings of the Eurobarometer (2010), this research showed that Northern Europeans think significantly more than respondents from other regions that a divide between low-, middle-, and high-income countries is likely to occur with the introduction of nanotechnologies in agriculture. Thus new studies should focus on whether individuals' risk perceptions differ depending on their characteristics and on the topic under investigation (e.g. nanotechnologies, GMOs, etc.). Furthermore, future research should also inspect whether there is a shift in opinion between respondents from different European regions and why this shift in opinions occurs. Lastly, besides the main research questions and related hypotheses, in this study also respondents' perceptions towards whether NGOs campaigns and attitudes towards GMOs are influencing the development and commercialization of nanotechnologies in agriculture. Overall, respondents had rather homogeneous opinions towards NGOs and GMOs. This can be clearly observed in Figure 8, where these questions have some of the highest average response (see Appendix III, table 1d), indicating that respondents believe that both aspects hamper the advancement of nanotechnologies in agriculture. Furthermore, non-European researchers and experts significantly believe more than Europeans that the criticism about GM crops will influence the development and commercialization of nanotechnologies in agriculture. Hence, given the great expectations towards nanotechnologies, especially from the Horizon 2020 Programme (European Commission, 2014), these findings should be taken into consideration for further legislation and for promoting nanotechnologies in agriculture.

It is thus suggested for the majority of the arguments taken into consideration in this chapter, to conduct further surveys or interviews.

Chapter 6 – Conclusions

The aim of this study was to investigate what researchers and experts' perceptions are towards the European legislation for the development and commercialization of nanotechnologies in agriculture. After having analysed their perceptions, the following conclusions can be made. First of all, the definition of nanotechnologies recommended by the European Commission is considered appropriate by both researchers and expert, regardless their background characteristics (socio-economic, demographic and knowledge characteristics). Second, researchers and experts' opinions in relation to the risk assessment and risk management regulatory framework are similar across their backgrounds as well. In fact, these regulations are perceived as strict by the 70.3% of the sample, and more than half believed that these regulations do not encourage the development and commercialization of nanotechnologies in agriculture. Third, researchers and experts' ideas are extremely polarized with regard to the recommendations to conduct a responsible research and innovation process.

It is thus essential for European policy makers to take into consideration all these aspect in drawing up new legislation on nanotechnology, and in promoting a responsible research and innovation process that is suitable for all stakeholders. To encourage this policy-making process, further research should be performed. In particular, surveys or interviews could be conducted to investigate (1) which factors determine researchers and experts' opinions on the appropriateness of nanotechnology definition and (2) whether a standardized regulatory framework tailored to nanotechnologies would be perceived by researchers and experts as favouring the introduction of nanotechnologies in agriculture.

This research also revealed that researchers and experts strongly believe that NGOs activities and criticism about GMOs will have negative spillover effects on the development and commercialization of nanotechnologies in agriculture. In particular, it seems likely that the introduction of nanotechnologies in agriculture will face the same barriers as GMOs. European policy makers should take into consideration these aspects an set up strategies to contain such negative spillover effects.

The factor analysis showed that the researchers and experts have four perception factors[12]: the first relates to the impediment of several factors (NGOs, GMOs, inadequate regulations and nanotechnologies (eco-)toxicological uncertainties) on the development and commercialization of agro-nanotechnologies. The second, grasps opinions towards the European legislation. The third factor reports the perception of NGOs and GMOs barriers to the advancement of nanotechnologies. Finally, the fourth reflects individuals' opinion polarization on the recommendations to conduct a responsible research and innovation process.

The cluster analysis, based on the four perception factors, shows the existence of five groups of researchers and experts' perceptions towards European legislation[13]: (1) researchers and experts that are confident in the development and commercialization of nanotechnologies in agriculture; (2) researchers and experts that recognize GMOs and NGOs barriers to the advancement of the technology; (3) those who are skeptic towards European legislation; (4) those that consider appropriate the definition of nanotechnologies, and (5) researchers and experts' opinions polarization on the recommendations to conduct a responsible research and innovation process.

As no study proposed itself to investigate researchers and experts' perceptions on the European legislation tailored to nanotechnologies, this research provides novel insights and contribute to enrich the

[12] General_blockage, Fundamentals, Foreign_blockage, RRI_expectations.
[13] CDC = Confidence in the development and commercialization of agro-nanotechnologies; GNB = GMOs and NGOs barriers; LS = Legislation skepticism; DA = Definition acceptance; RRID = RRI dualism.

understanding surrounding the development and introduction of new technologies in agriculture. In particular, what researchers and experts think about nanotechnologies regulations, and how they feel and behave in the development and commercialization processes. As policy makers have to promulgate regulations and recommendations to ensure both competitiveness and safety measures, the point of view of all stakeholders are relevant for an effective implementation of legislation tailored to nanotechnologies.

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Appendix I – Online questionnaire

Background information

1. What is your gender?

- ○ Male
- ○ Female

2. What is your age?

- ○ < 24
- ○ 25-34
- ○ 35-44
- ○ 45-54
- ○ 55-64
- ○ > 64

3. What is your marital status?

- ○ Married
- ○ Widowed
- ○ Divorced / Separated
- ○ Living with a partner
- ○ Single (never married)

4. Do you have child(ren)?

- ◯ Yes
- ◯ No

5. If yes, what is his / her / their age?
(multiple choice for 2+ children)

- ◯ Under age 18
- ◯ Aged 18
- ◯ Older age 18

6. In which country do you work?

Drop-down list

7. Your employment position is:

- ◯ Researcher (public sector - e.g. university)
- ◯ Researcher (private sector - e.g. company)
- ◯ Employee (public sector - e.g. university)
- ◯ Employee (private sector - e.g. company)
- ◯ Other ___________________________________

8. Your knowledge about agro-nanotechnologies - e.g. nano-encapsulated pesticides, fertilizers insecticides - is:

- Excellent
- Good
- Average
- Poor
- Terrible

European definition of nanotechnologies

9. According to the European Commission, nanotechnology is "a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm - 100 nm. In specific cases and where
warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50 % may be replaced by a threshold between 1 and 50 %". This definition of nanotechnology used in the European legislation is:

- Extremely appropriate
- Moderately appropriate
- Slightly appropriate
- Neither appropriate nor inappropriate
- Slightly inappropriate
- Moderately inappropriate
- Extremely inappropriate
- Not sure

10. To what extent is the European definition of nanotechnology laying the foundations for a regulatory framework capable of incentivizing the development of nanotechnologies in agriculture?
(1 = not at all; 5 = neutral; 9 = extremely)

0	1	2	3	4	5	6	7	8	9	Not sure
○	○	○	○	○	○	○	○	○	○	○

11. To what extent is the European definition of nanotechnology laying the foundations for a regulatory framework capable of incentivizing the commercialization of nanotechnologies in agriculture?
(1 = not at all; 5 = neutral; 9 = extremely)

0	1	2	3	4	5	6	7	8	9	Not sure
○	○	○	○	○	○	○	○	○	○	○

Risk assessment and risk management frameworks

12. How familiar are you with the Risk Assessment and Risk Management regulatory frameworks set by the European Union?

○ Extremely familiar

○ Very familiar

○ Moderately familiar

○ Slightly familiar

○ Not familiar at all

13. In order to be able to commercialize agro-nanotechnologies, the European risk assessment and risk management regulatory frameworks is:

○ Far too strict

○ Moderately strict

○ Slightly strict

○ Neither strict nor flexible

○ Slightly flexible

○ Moderately flexible

○ Far too flexible

○ Not sure

14. To what extent does the European legislation (Risk Assessment, Risk management frameworks) encourage the development and commercialization of nanotechnologies in agriculture?
(1 = not at all; 5 = neutral; 9 = extremely)

0	1	2	3	4	5	6	7	8	9	Not sure
○	○	○	○	○	○	○	○	○	○	○

15. To what extent are NGOs anti-nano campaigns successful in undermining the development of nanotechnologies in agriculture?
(1 = not at all; 5 = neutral; 9 = extremely)

0	1	2	3	4	5	6	7	8	9	Not sure
○	○	○	○	○	○	○	○	○	○	○

16. To what extent are NGOs regulatory requests about safety measures successful in slowing down the commercialization process of nanotechnologies in agriculture?
(1 = not at all; 5 = neutral; 9 = extremely)

0	1	2	3	4	5	6	7	8	9	Not sure
○	○	○	○	○	○	○	○	○	○	○

Responsible Research and Innovation framework

17. How familiar are you with the concept of Responsible research and Innovation (RRI) recommended by the European Union?

○ Extremely familiar

○ Very familiar

○ Moderately familiar

○ Slightly familiar

○ Not familiar at all

18. What is, in your opinion, a responsible research and innovation process?

____

19. According to the European Union, "RRI is an inclusive approach to research and innovation (R&I), to ensure that societal actors work together during the whole research and innovation process. It aims to better align both the process and outcomes of R&I, with the values, needs and expectations of European society."
To what extent is a Responsible Research and Innovation (RRI) fundamental in the development process of nanotechnologies in agriculture?
(1 = not at all; 5 = neutral; 9 = extremely)

0	1	2	3	4	5	6	7	8	9	Not sure
○	○	○	○	○	○	○	○	○	○	○

20. While researching and developing agro-nanotechnologies, the researcher (or the research organization) should:

	Strongly agree	Agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly disagree	Not sure
Develop a nanotechnology that is socially desirable								
Involve the society in the research process								
Comprehensively explain its activities to the public								
Foresee unintended impact(s) of the nanotechnology								
Be held responsible of the outcomes (positive or negative) of the nanotechnology								
Develop a nanotechnology that will solve "grand challenges" (e.g. resource depletion)								
Being transparent (share knowledge, no information asymmetries)								

21. In your work environment, to what extent is to conduct a Responsible Research and Innovation (RRI) process encouraged?
(1 = not at all; 5 = neutral; 9 = extremely)

0	1	2	3	4	5	6	7	8	9	Not sure

22. How is a Responsible Research and Innovation process encouraged in your work environment?

____

23. After the European recommendation for conducting a RRI process, the development of nanotechnologies in agriculture has changed in practice.

○ Strongly agree

○ Agree

○ Somewhat agree

○ Neither agree nor disagree

○ Somewhat disagree

○ Disagree

○ Strongly disagree

○ Not sure

Relation between GMOs and agro-nanotechnologies

24. Europe is characterized by a widespread criticism about GM crops. Do you think this critical approach is influencing the development and commercialization of nanotechnologies in agriculture?

○ Definitely yes

○ Probably yes

○ Might or might not

○ Probably not

○ Definitely not

○ Not sure

25. How is the critical approach described above able to influence the development and commercialization of agro-nanotechnologies?

____

26. After the regulatory framework built upon the development of GMOs (i.e. risk assessment, risk management, responsible research and innovation process), do you think that researchers' scientific freedom is somehow been reduced?

◯ Yes

◯ No

27. To what extent is the blockage of GM crops possible to occur to nanotechnology applications in agriculture?
(1 = not at all; 5 = neutral; 9 = extremely)

0	1	2	3	4	5	6	7	8	9	Not sure
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

More general questions on agro-nanotechnologies

28. To what extent do the following aspects contribute in impeding the development of nanotechnologies in agriculture?
(1 = not at all; 5 = neutral; 9 = extremely)

	1	2	3	4	5	6	7	8	9	Not Sure
Lack of communication between science and society	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Inadequate regulations	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
NGOs campaigns	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Nanotechnology toxicological and ecotoxicological uncertainties	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Attitudes towards GMOs	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

29. To what extent do the following aspects contribute in impeding the commercialization of nanotechnologies in agriculture?
(1 = not at all; 5 = neutral; 9 = extremely)

	1	2	3	4	5	6	7	8	9	Not sure
Lack of communication between science and society	○	○	○	○	○	○	○	○	○	○
Inadequate regulations	○	○	○	○	○	○	○	○	○	○
NGOs campaigns	○	○	○	○	○	○	○	○	○	○
Nanotechnology toxicological and ecotoxicological uncertainties	○	○	○	○	○	○	○	○	○	○
Attitudes towards GMOs	○	○	○	○	○	○	○	○	○	○

30. Agro-nanotechnologies are not commercialized because of:
(multiple choice)

- ☐ The technology is not developed yet
- ☐ The strict regulatory requirements for their approval
- ☐ The concerns of societal blockage
- ☐ The technology is not marketable yet
- ☐ High production costs
- ☐ Cultural differences between European countries
- ☐ Other reasons ____
- ☐ Not sure

31. If agro-nanotechnologies are commercialized, it is likely that the divide between low-, middle-, and high-income countries will:

- ○ Extremely increase
- ○ Increase
- ○ Somewhat increase
- ○ Neither increase nor decrease
- ○ Somewhat decrease
- ○ Decrease
- ○ Extremely decrease
- ○ Not sure

End of Block: Default Question Block

Appendix II – Calinski-Harabasz F test

```
  ___  ____  ____  ____  ____ tm
 /__    /   ____/   /   ____/
___/   /   /___/   /   /___/   10.1   Copyright 1984-2009
  Statistics/Data Analysis            StataCorp
                                      4905 Lakeway Drive
                                      College Station, Texas 77845 USA
                                      800-STATA-PC        http://www.stata.com
                                      979-696-4600        stata@stata.com
                                      979-696-4601 (fax)

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                       Wageningen UR

Notes:
      1.  (/m# option or -set memory-) 1.00 MB allocated to data

. ssc install usespss
checking usespss consistency and verifying not already installed...
all files already exist and are up to date.

. usespss using "D:\data\MT_FA_Oblique_condensed_scale_BASELINE.sav"

. cluster kmeans FA_General_blockage FA_Fundamentals FA_Foreign_blockage FA_RRI_E, k(2) measure(L2) start(krandom)
cluster name: _clus_1

. cluster kmeans FA_General_blockage FA_Fundamentals FA_Foreign_blockage FA_RRI_E, k(3) measure(L2) start(krandom)
cluster name: _clus_2

. cluster kmeans FA_General_blockage FA_Fundamentals FA_Foreign_blockage FA_RRI_E, k(4) measure(L2) start(krandom)
cluster name: _clus_3

. cluster kmeans FA_General_blockage FA_Fundamentals FA_Foreign_blockage FA_RRI_E, k(5) measure(L2) start(krandom)
cluster name: _clus_4

. cluster kmeans FA_General_blockage FA_Fundamentals FA_Foreign_blockage FA_RRI_E, k(6) measure(L2) start(krandom)
cluster name: _clus_5

. cluster stop _clus_1, rule(duda) variables(FA_General_blockage FA_Fundamentals FA_Foreign_blockage FA_RRI_E)
rule(duda) allowed only with hierarchical clustering
r(198);

. cluster stop _clus_1, rule(calinski) variables(FA_General_blockage FA_Fundamentals FA_Foreign_blockage FA_RRI_E)
```

Number of clusters	Calinski/ Harabasz pseudo-F
2	65.86

```
. cluster stop _clus_2, rule(calinski) variables(FA_General_blockage FA_Fundamentals FA_Foreign_blockage FA_RRI_E)
```

Number of clusters	Calinski/ Harabasz pseudo-F
3	56.22

```
. cluster stop _clus_3, rule(calinski) variables(FA_General_blockage FA_Fundamentals FA_Foreign_blockage FA_RRI_E)
```

Number of clusters	Calinski/ Harabasz pseudo-F
4	51.38

```
. cluster stop _clus_4, rule(calinski) variables(FA_General_blockage FA_Fundamentals FA_Foreign_blockage FA_RRI_E)
```

Number of clusters	Calinski/ Harabasz pseudo-F
5	56.76

```
. cluster stop _clus_5, rule(calinski) variables(FA_General_blockage FA_Fundamentals FA_Foreign_blockage FA_RRI_E)
```

Number of clusters	Calinski/ Harabasz pseudo-F
6	55.32

```
. cluster kmeans FA_General_blockage FA_Fundamentals FA_Foreign_blockage FA_RRI_E, k(7) measure(L2) start(krandom)
cluster name: _clus_6

. cluster stop _clus_6, rule(calinski) variables(FA_General_blockage FA_Fundamentals FA_Foreign_blockage FA_RRI_E)
```

Number of clusters	Calinski/ Harabasz pseudo-F
7	55.65

```
.
```

Appendix III – Respondents' characteristics

Table 1a – Socio-economic and demographic characteristics of respondents.

Characteristics		Frequencies and Descriptives				
		Frequency	Percent	Mean	St. Deviation	CoV (%)
Gender				0.72	0.450	62.5
Female		42	27.8			
Male		109	72.2			
Age				4.24	1.118	26.4
25-34		9	6.0			
35-44		32	21.2			
45-54		45	29.8			
55-64		44	29.1			
> 64		21	13.9			
Marital status				1.74	1.383	79.5
Married		112	74.2			
Widowed		5	3.3			
Divorced / Separated		12	7.9			
Living with a partner		5	3.3			
Single (never married)		17	11.3			
Children				0.71	0.456	64.2
No		44	29.1			
Yes		107	70.9			
	Under age 18	56	47.5			
	Aged 18	1	0.8			
	Older age 18	61	51.7			
Employment				1.69	1.391	82.3
Public researcher		57	37.7			
Private researcher		17	11.3			
Public Employee		20	13.2			
Private Employee		26	17.2			
Other		31	20.5			
Country_membership				0.623	0.486	78.1
Not European		57	37.7			
European		94	62.3			
European_countries				18.202	9.834	54.0
Austria		2	1.3			
Belgium		9	6			
Czech Republic		1	0.7			
Denmark		1	0.7			
Finland		1	0.7			
France		4	2.6			
Germany		17	11.3			
Hungary		1	0.7			
Ireland		2	1.3			
Italy		11	7.3			
Latvia		1	0.7			
Netherlands		9	6			
Norway		3	2			
Poland		1	0.7			
Portugal		7	4.6			
Slovakia		1	0.7			
Spain		4	2.6			
Sweden		1	0.7			
Switzerland		9	6			
United Kingdom		9	6			

Note: CoV is the Coefficient of Variation and is expressed as percentage. No_foreign_Country includes all European countries.

Table 1b – Background knowledge of respondents.

Characteristics	Frequency	Percent	Mean	St. Deviation	CoV (%)
	Frequencies and Descriptives				
Nano_knowledge			3.04	0.944	31.1
Excellent	9	6.0			
Good	31	20.5			
Average	62	41.1			
Poor	43	28.5			
Terrible	6	4.0			
RARM_familiar			3.19	1.168	36.6
Extremely familiar	13	8.6			
Very familiar	29	19.2			
Moderately familiar	49	32.5			
Slightly familiar	37	24.5			
Not familiar at all	23	15.2			
RRI_familiar			3.77	1.212	32.1
Extremely familiar	5	3.3			
Very familiar	21	13.9			
Moderately familiar	38	25.2			
Slightly familiar	26	17.2			
Not familiar at all	61	40.4			
Sci_freedom_reduced			0.64	0.481	75.2
No	52	34.4			
Yes	94	62.3			

Note: CoV is the Coefficient of Variation and is expressed as percentage.

Table 1c – Survey responses divided by each section.

Survey sections	Variables	Frequency	Percent	Mean	St. Deviation	CoV (%)
		Frequencies and Descriptives				
European definition of nanotechnologies						
	Definition appropriateness					
	Not sure	43	28.5	2.88	2.12	73.61
	Inappropriate	9	6			
	Slightly inappropriate	7	4.6			
	Neither appropriate nor inappropriate	11	7.3			
	Slightly appropriate	26	17.2			
	Appropriate	55	36.4			
	Development effects			2.93	2.271	77.51
	Not sure	41	27.2			
	Not at all	5	3.3			
	Moderately-	24	15.9			
	Slightly-	10	6.6			
	Neutral	24	15.9			
	Slightly+	20	13.2			
	Moderately+	25	16.6			
	Extremely	2	1.3			
	Commercialization effects			2.81	2.247	79.96
	Not sure	43	28.5			
	Not at all	4	2.6			
	Moderately-	28	18.5			
	Slightly-	12	7.9			
	Neutral	17	11.3			
	Slightly+	23	15.2			
	Moderately+	23	15.2			
	Extremely	1	0.7			
Risk Assessment and Risk Management frameworks						
	Legislation flexibility			1.34	1.452	108.36
	Not sure	50	33.1			
	Strict	54	35.8			
	Slightly strict	17	11.3			
	Neither strict nor flexible	16	10.6			
	Slightly flexible	3	2			
	Flexible	11	7.3			

	Development and Commercialization effects			2.36	2.108	89.32
	Not sure	48	31.8			
	Not at all	6	4			
	Moderately-	39	25.8			
	Slightly-	11	7.3			
	Neutral	12	7.9			
	Slightly+	20	13.2			
	Moderately+	14	9.3			
	Extremely	1	0.7			
NGOs activities						
	No development effects			3.75	2.533	67.55
	Not sure	37	24.5			
	Not at all	1	0.7			
	Moderately-	13	8.6			
	Slightly-	8	5.3			
	Neutral	14	9.3			
	Slightly+	22	14.6			
	Moderately+	43	28.5			
	Extremely	13	8.6			
	No commercialization effects			3.73	2.671	71.61
	Not sure	42	27.8			
	Not at all	1	0.7			
	Moderately-	10	6.6			
	Slightly-	8	5.3			
	Neutral	10	6.6			
	Slightly+	21	13.9			
	Moderately+	40	26.5			
	Extremely	19	12.6			
Responsible Research and Innovation framework						
	RRI importance			4.08	2.531	62.03
	Not sure	30	19.9			
	Not at all	3	2			
	Moderately-	15	9.9			
	Slightly-	4	2.6			
	Neutral	15	9.9			
	Slightly+	10	6.6			
	Moderately+	57	37.7			
	Extremely	17	11.3			
	RRI is encouraged			3.46	2.513	72.63
	Not sure	33	21.9			
	Not at all	16	10.6			
	Moderately-	10	6.6			
	Slightly-	5	3.3			
	Neutral	27	17.9			
	Slightly+	7	4.6			
	Moderately+	42	27.8			
	Extremely	11	7.3			
	RRI change scientific practice			1.65	1.848	112.00
	Not sure	74	49			
	Disagree	5	3.3			
	Somewhat disagree	8	5.3			
	Neither agree nor disagree	28	18.5			
	Somewhat agree	19	12.6			
	Agree	12	7.9			
	The researcher should:					
	Socially desirable			2.93	1.926	65.73
	Not sure	10	6.6			
	Disagree	54	35.8			
	Somewhat disagree	5	3.3			
	Neither agree nor disagree	7	4.6			
	Somewhat agree	18	11.9			
	Agree	57	37.7			
	Involve the society			2.94	1.87	63.61
	Not sure	9	6			
	Disagree	48	31.8			
	Somewhat disagree	12	7.9			
	Neither agree nor disagree	13	8.6			
	Somewhat agree	12	7.9			
	Agree	57	37.7			
	Explain activities			2.99	1.975	66.05
	Not sure	9	6			
	Disagree	57	37.7			
	Somewhat disagree	2	1.3			
	Neither agree nor disagree	7	4.6			
	Somewhat agree	10	6.6			
	Agree	66	43.7			
	Foresee unintended impacts			3.26	2.016	61.84

	Not sure	10	6.6			
	Disagree	47	31.1			
	Somewhat disagree	6	4			
	Neither agree nor disagree	1	0.7			
	Somewhat agree	4	2.6			
	Agree	83	55			
	Responsible_outcomes			2.95	1.893	64.17
	Not sure	10	6.6			
	Disagree	48	31.8			
	Somewhat disagree	11	7.3			
	Neither agree nor disagree	11	7.3			
	Somewhat agree	13	8.6			
	Agree	58	38.4			
	Solve grand challenges			2.65	1.909	72.04
	Not sure	13	8.6			
	Disagree	61	40.4			
	Somewhat disagree	4	2.6			
	Neither agree nor disagree	5	3.3			
	Somewhat agree	24	15.9			
	Agree	44	29.1			
	Be transparent			3.23	1.974	61.11
	Not sure	10	6.6			
	Disagree	47	31.1			
	Somewhat disagree	3	2			
	Neither agree nor disagree	5	3.3			
	Somewhat agree	11	7.3			
	Agree	75	49.7			
Relation between GMOs and agro-nanotechnologies						
	Development and commercialization effects			3.68	1.561	42.42
	Not sure	17	11.3			
	Definitely not	2	1.3			
	Probably not	5	3.3			
	Might or might not	10	6.6			
	Probably yes	64	42.4			
	Definitely yes	48	31.8			
	GMO inclination to agro-nano			4.74	2.334	49.24
	Not sure	19	12.6			
	Not at all	4	2.6			
	Moderately-	8	5.3			
	Slightly-	1	0.7			
	Neutral	14	9.3			
	Slightly+	16	10.6			
	Moderately+	55	36.4			
	Extremely	29	19.2			
General questions about agro-nanotechnologies						
	Nano increase divide between low-, middle-, high-income countries			2.81	1.873	66.65
	Not sure	36	23.8			
	Disagree	4	2.6			
	Somewhat disagree	8	5.3			
	Neither agree nor disagree	37	24.5			
	Somewhat agree	26	17.2			
	Agree	35	23.2			
	Factors that impede nano development: Lack communication between science and society			4.64	2.222	47.89
	Not sure	15	9.9			
	Not at all	4	2.6			
	Moderately-	11	7.3			
	Slightly-	8	5.3			
	Neutral	16	10.6			
	Slightly+	12	7.9			
	Moderately+	57	37.7			
	Extremely	23	15.2			
	Inadequate regulations			3.8	2.285	60.13
	Not sure	22	14.6			
	Not at all	7	4.6			
	Moderately-	21	13.9			
	Slightly-	6	4			
	Neutral	19	12.6			
	Slightly+	22	14.6			
	Moderately+	41	27.2			
	Extremely	8	5.3			
	NGOs campaigns			4.86	2.236	46.01
	Not sure	14	9.3			
	Not at all	3	2			
	Moderately-	11	7.3			
	Slightly-	6	4			

Neutral	16	10.6			
Slightly+	7	4.6			
Moderately+	55	36.4			
Extremely	34	22.5			
(Eco-)toxicological uncertainties			4.18	2.291	54.81
Not sure	23	15.2			
Not at all	1	0.7			
Moderately-	13	8.6			
Slightly-	8	5.3			
Neutral	20	13.2			
Slightly+	20	13.2			
Moderately+	48	31.8			
Extremely	13	8.6			
Attitudes towards GMOs			4.97	2.269	45.65
Not sure	13	8.6			
Not at all	6	4			
Moderately-	10	6.6			
Slightly-	3	2			
Neutral	11	7.3			
Slightly+	13	8.6			
Moderately+	49	32.5			
Extremely	41	27.2			
Factors that impede nano commercialization: Lack communication between science and society					
Not sure	15	9.9	4.92	2.238	45.49
Not at all	4	2.6			
Moderately-	9	6			
Slightly-	3	2			
Neutral	11	7.3			
Slightly+	10	6.6			
Moderately+	64	42.4			
Extremely	30	19.9			
Inadequate regulations			4.08	2.44	59.80
Not sure	24	15.9			
Not at all	7	4.6			
Moderately-	13	8.6			
Slightly-	6	4			
Neutral	17	11.3			
Slightly+	14	9.3			
Moderately+	48	31.8			
Extremely	17	11.3			
NGOs campaigns			4.95	2.38	48.08
Not sure	17	11.3			
Not at all	5	3.3			
Moderately-	6	4			
Slightly-	4	2.6			
Neutral	15	9.9			
Slightly+	8	5.3			
Moderately+	44	29.1			
Extremely	47	31.1			
(Eco-)toxicological uncertainties			4.4	2.327	52.89
Not sure	20	13.2			
Not at all	2	1.3			
Moderately-	16	10.6			
Slightly-	5	3.3			
Neutral	14	9.3			
Slightly+	15	9.9			
Moderately+	56	37.1			
Extremely	18	11.9			
Attitudes towards GMOs			5.07	2.324	45.84
Not sure	15	9.9			
Not at all	6	4			
Moderately-	6	4			
Slightly-	4	2.6			
Neutral	9	6			
Slightly+	7	4.6			
Moderately+	54	35.8			
Extremely	45	29.8			
Reasons for which nanotechnologies are not yet commercialized:					
The technology is not developed	45	15.3			
Strict regulatory requirements	47	15.9			
Societal blockage	61	20.7			
The technology is not marketable	51	17.3			
High production costs	30	10.2			
Cultural differences between EU countries	22	7.5			
Not sure	39	13.2			

Note: CoV is the Coefficient of Variation and is expressed as a percentage.

Table 1d – Overall mean and percentages of responses for each option included in each survey question, with the opt-out option excluded.

Variable	Scale								Mean
	Not at all	Moderately-	Slightly-	Neutral	Slightly+	Moderately+	Extremely	Total	
Nano_def_develop	4.5	21.8	9.1	21.8	18.2	22.7	1.8	100	4.03
Nano_def_comm	3.7	25.9	11.1	15.7	21.3	21.3	0.9	100	3.93
RARM_develop_comm	5.8	37.9	10.7	11.7	19.4	13.6	1.0	100	3.46
NGO_develop	0.9	11.4	7.0	12.3	19.3	37.7	11.4	100	4.96
NGO_comm	0.9	9.2	7.3	9.2	19.3	36.7	17.4	100	5.17
RRI_importance	2.5	12.4	3.3	12.4	8.3	47.1	14.0	100	5.09
RRI_encouraged	13.6	8.5	4.2	22.9	5.9	35.6	9.3	100	4.43
GMO_scenario_nano	3.1	6.3	0.8	11.0	12.6	43.3	22.8	100	5.45
Develop_lack_communications	3.1	8.4	6.1	12.2	9.2	43.5	17.6	100	5.17
Develop_bad_regulations	5.6	16.9	4.8	15.3	17.7	33.1	6.5	100	4.48
Develop_NGO	2.3	8.3	4.5	12.1	5.3	41.7	25.8	100	5.38
Develop_uncertainty	0.8	10.6	6.5	16.3	16.3	39.0	10.6	100	4.96
Develop_attitudes_GMO	4.5	7.5	2.3	8.3	9.8	36.8	30.8	100	5.45
Comm_lack_communications	3.1	6.9	2.3	8.4	7.6	48.9	22.9	100	5.49
Comm_bad_regulations	5.7	10.7	4.9	13.9	11.5	39.3	13.9	100	4.89
Comm_NGO	3.9	4.7	3.1	11.6	6.2	34.1	36.4	100	5.60
Comm_uncertainty	1.6	12.7	4.0	11.1	11.9	44.4	14.3	100	5.10
Comm_attitudes_GMO	4.6	4.6	3.1	6.9	5.3	41.2	34.4	100	5.65

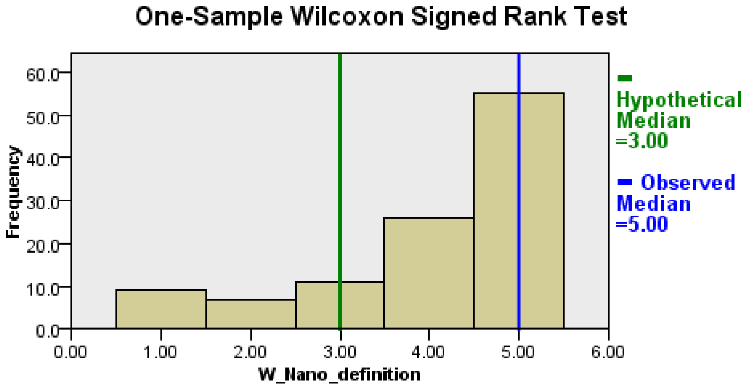
Variable	Scale						Mean
	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Total	
RRI_socially_desirable	38.3	3.5	5.0	12.8	40.4	100	3.13
RRI_involve_society	33.8	8.5	9.2	8.5	40.1	100	3.13
RRI_explain_activities	40.1	1.4	4.9	7.0	46.5	100	3.18
RRI_foresee_bad_impacts	33.3	4.3	0.7	2.8	58.9	100	3.50
RRI_responsible_outcomes	34.0	7.8	7.8	9.2	41.1	100	3.16
RRI_grand_challenges	44.2	2.9	3.6	17.4	31.9	100	2.90
RRI_transparency	33.3	2.1	3.5	7.8	53.2	100	3.45
RRI_change_practice	6.9	11.1	38.9	26.4	16.7	100	3.35
Nano_divide	3.6	7.3	33.6	23.6	31.8	100	3.73

Scale	Nano_definition
	Percent
Inappropriate	8.3
Slightly inappropriate	6.5
Neither appropriate nor inappropriate	10.2
Slightly appropriate	24.1
Appropriate	50.9
Total	100
Mean	4.03

Scale	RARM_flexibility
	Percent
Strict	53.5
Slightly strict	16.8
Neither strict nor flexible	15.8
Slightly flexible	3.0
Flexible	10.9
Total	100
Mean	2.01

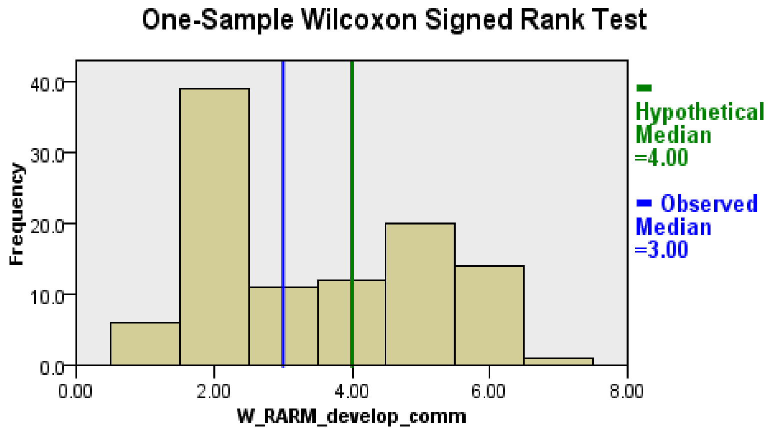
Scale	GMO_influence_nano
	Percent
Definitely not	1.6
Probably not	3.9
Might or might not	7.8
Probably yes	49.6
Definitely yes	37.2
Total	100
Mean	4.17

Table 2a – Respondents' opinions on the acceptance on the definition of nanotechnologies

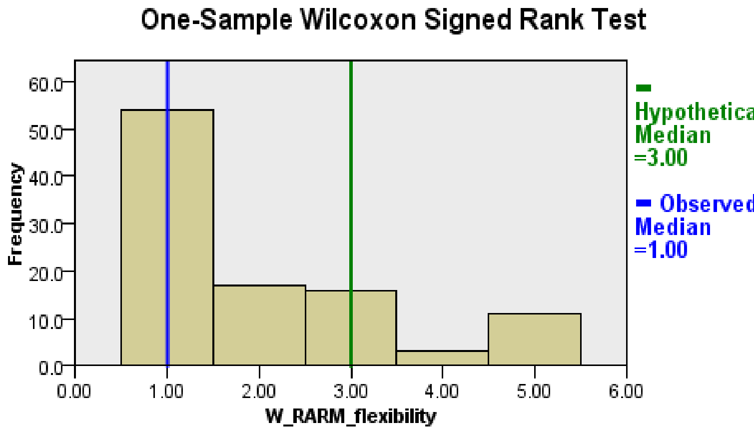


Total N	108
Test Statistic	4,044.500
Standard Error	266.511
Standardized Test Statistic	6.259
Asymptotic Sig. (2-sided test)	.000

Table 2b – Respondents' opinions on RARM regulations.



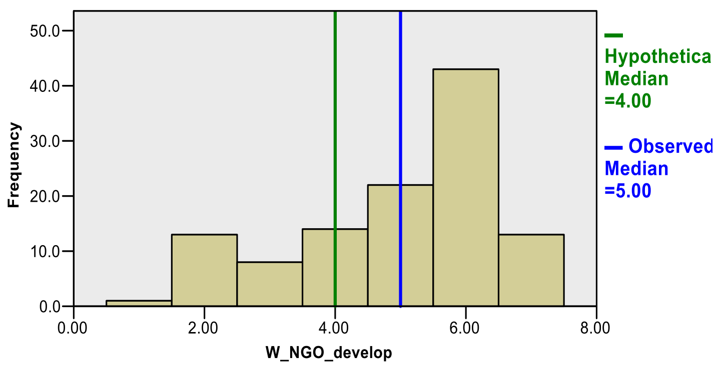
Total N	103
Test Statistic	1,220.000
Standard Error	245.171
Standardized Test Statistic	-3.561
Asymptotic Sig. (2-sided test)	.000



Total N	101
Test Statistic	614.500
Standard Error	214.936
Standardized Test Statistic	-5.644
Asymptotic Sig. (2-sided test)	.000

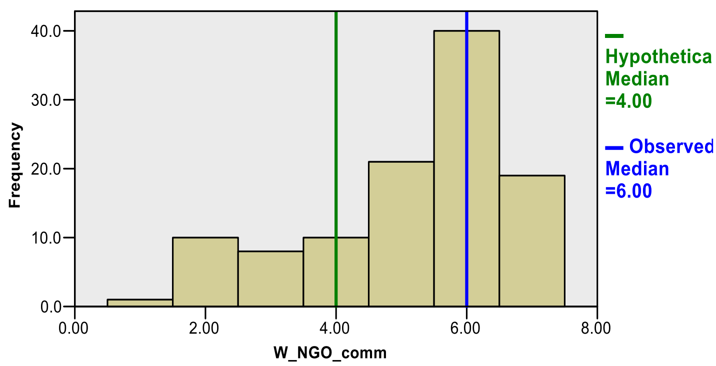
Table 2c – Respondents' opinions on NGOs and GMOs influence on agro-nanotechnologies.

One-Sample Wilcoxon Signed Rank Test



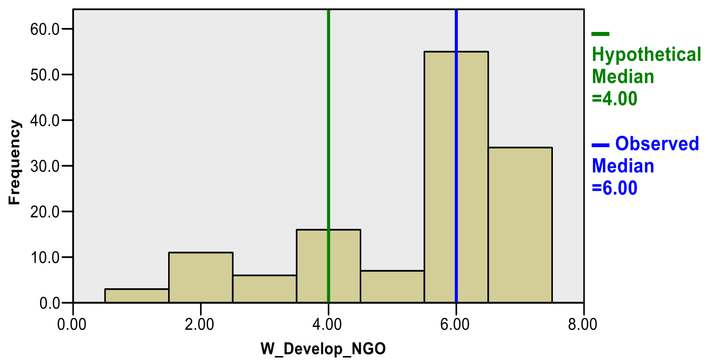
Total N	114
Test Statistic	4,072.000
Standard Error	283.392
Standardized Test Statistic	5.459
Asymptotic Sig. (2-sided test)	.000

One-Sample Wilcoxon Signed Rank Test



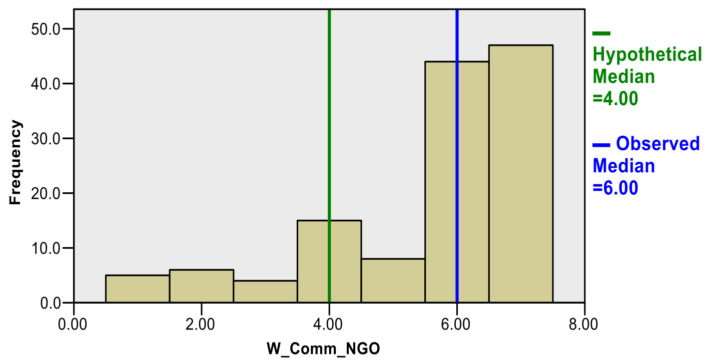
Total N	109
Test Statistic	4,195.500
Standard Error	280.732
Standardized Test Statistic	6.129
Asymptotic Sig. (2-sided test)	.000

One-Sample Wilcoxon Signed Rank Test



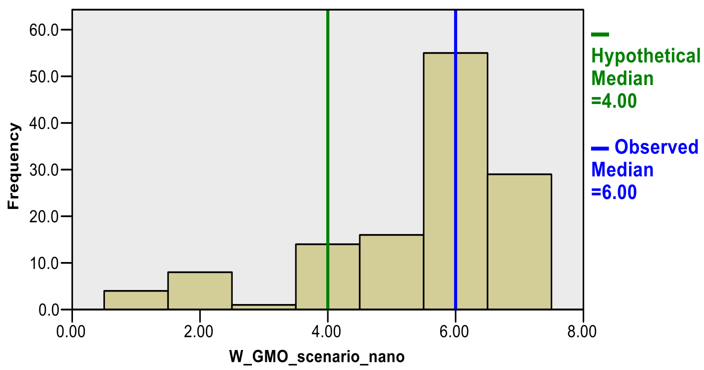
Total N	132
Test Statistic	5,938.500
Standard Error	353.091
Standardized Test Statistic	7.209
Asymptotic Sig. (2-sided test)	.000

One-Sample Wilcoxon Signed Rank Test



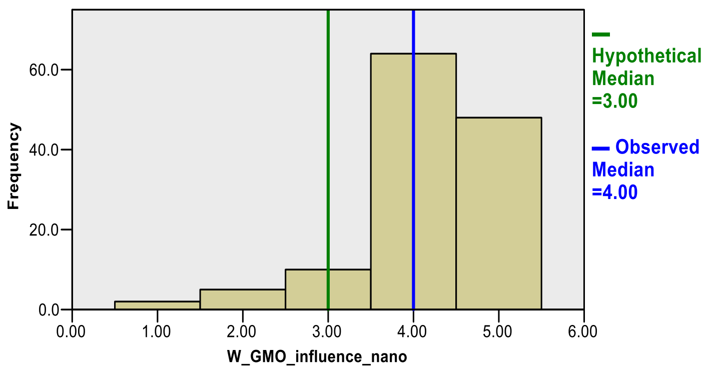
Total N	129
Test Statistic	5,861.500
Standard Error	345.723
Standardized Test Statistic	7.474
Asymptotic Sig. (2-sided test)	.000

One-Sample Wilcoxon Signed Rank Test



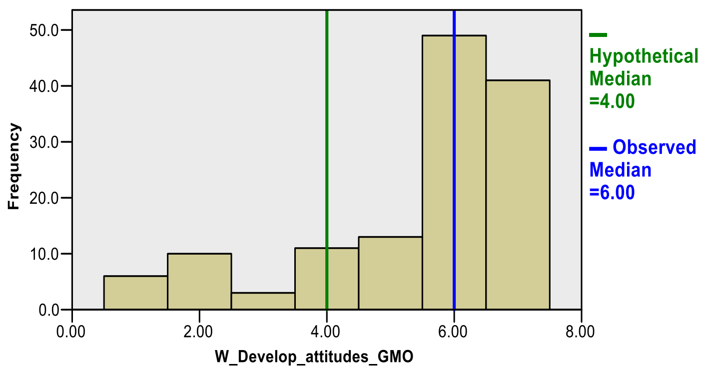
Total N	127
Test Statistic	5,652.000
Standard Error	340.271
Standardized Test Statistic	7.146
Asymptotic Sig. (2-sided test)	.000

One-Sample Wilcoxon Signed Rank Test



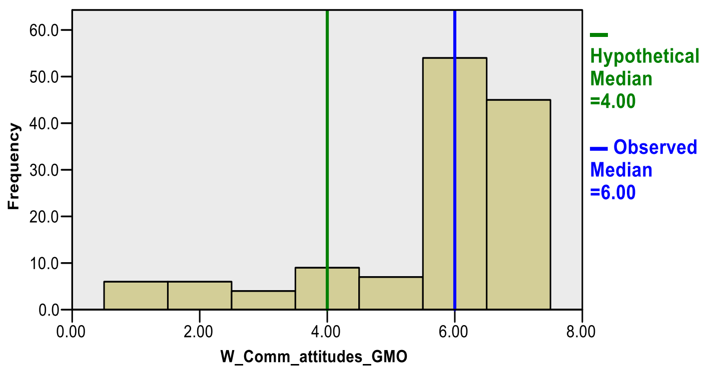
Total N	129
Test Statistic	6,776.000
Standard Error	364.362
Standardized Test Statistic	8.799
Asymptotic Sig. (2-sided test)	.000

One-Sample Wilcoxon Signed Rank Test



Total N	133
Test Statistic	6,423.500
Standard Error	382.964
Standardized Test Statistic	6.977
Asymptotic Sig. (2-sided test)	.000

One-Sample Wilcoxon Signed Rank Test



Total N	131
Test Statistic	6,648.000
Standard Error	381.965
Standardized Test Statistic	7.583
Asymptotic Sig. (2-sided test)	.000

Appendix IV – Respondents’ characteristics and background knowledge

Table 1 – Background knowledge and socio-economic and demographic characteristics of respondents.

Background knowledge	Socio-demographic characteristic						
	Gender	Age	Marital status	Children	Country_membership	No_foreign_Country	Employment
Nano_knowledge							
Chi-square	0.241 (1)	12.999 (4)	1.750 (4)	0.012 (1)	0.001 (1)	23.740 (19)	1.641 (3)
P-value	0.624	0.011**	0.782	0.914	0.971	0.206	0.65
RARM_familiar							
Chi-square	0.06 (1)	6.955 (4)	8.038 (4)	0.009 (1)	0.035 (1)	23.469 (19)	4.585 (3)
P-value	0.807	0.138	0.09	0.923	0.852	0.217	0.205
RRI_familiar							
Chi-square	0.013 (1)	7.245 (4)	1.652 (4)	1.180 (1)	1.145 (1)	19.868 (19)	4.559 (3)
P-value	0.91	0.124	0.8	0.178	0.285	0.403	0.207
Sci_freedom_reduced							
Chi-square	0.459 (1)	5.620 (4)	3.114 (4)	0.247 (1)	1.359 (1)	14.726 (19)	3.590 (3)
P-value	0.498	0.229	0.539	0.619	0.244	0.74	0.309

Note: degrees of freedom are in parentheses. Country_membership is a binary variable to identify respondents that are European and respondents that are not. No_foreign_Country represents respondents’ membership to each European country.

**Significance at 0.05 level.

Appendix V – Comparison of survey questions and respondents characteristics

Figure 1 - Knowledge on nanotechnologies and respondents' age.

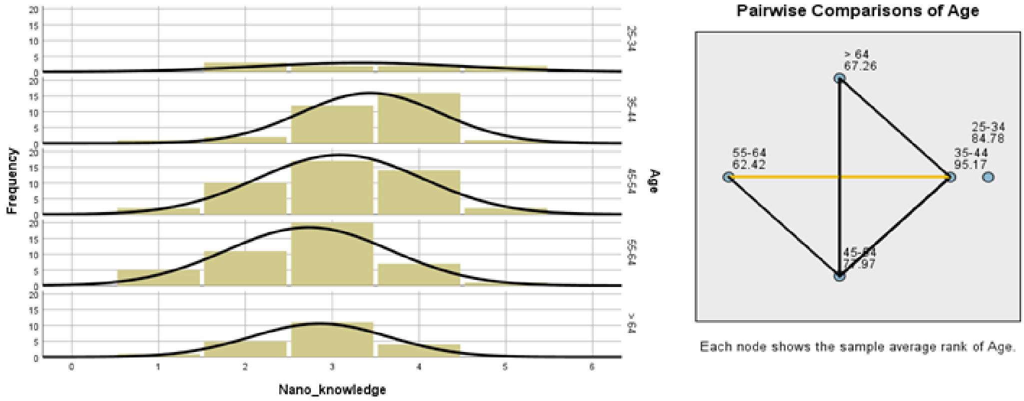


Figure 2 – Respondents' age and significant survey questions.

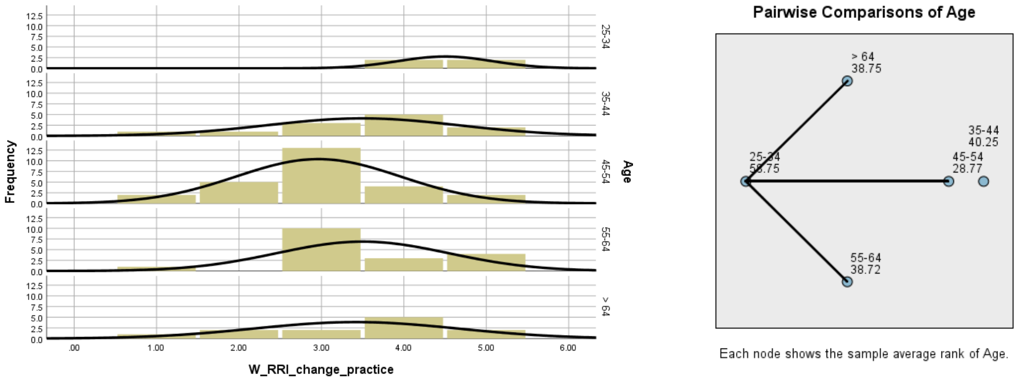


Figure 3 – Respondents' employment type and significant survey questions.

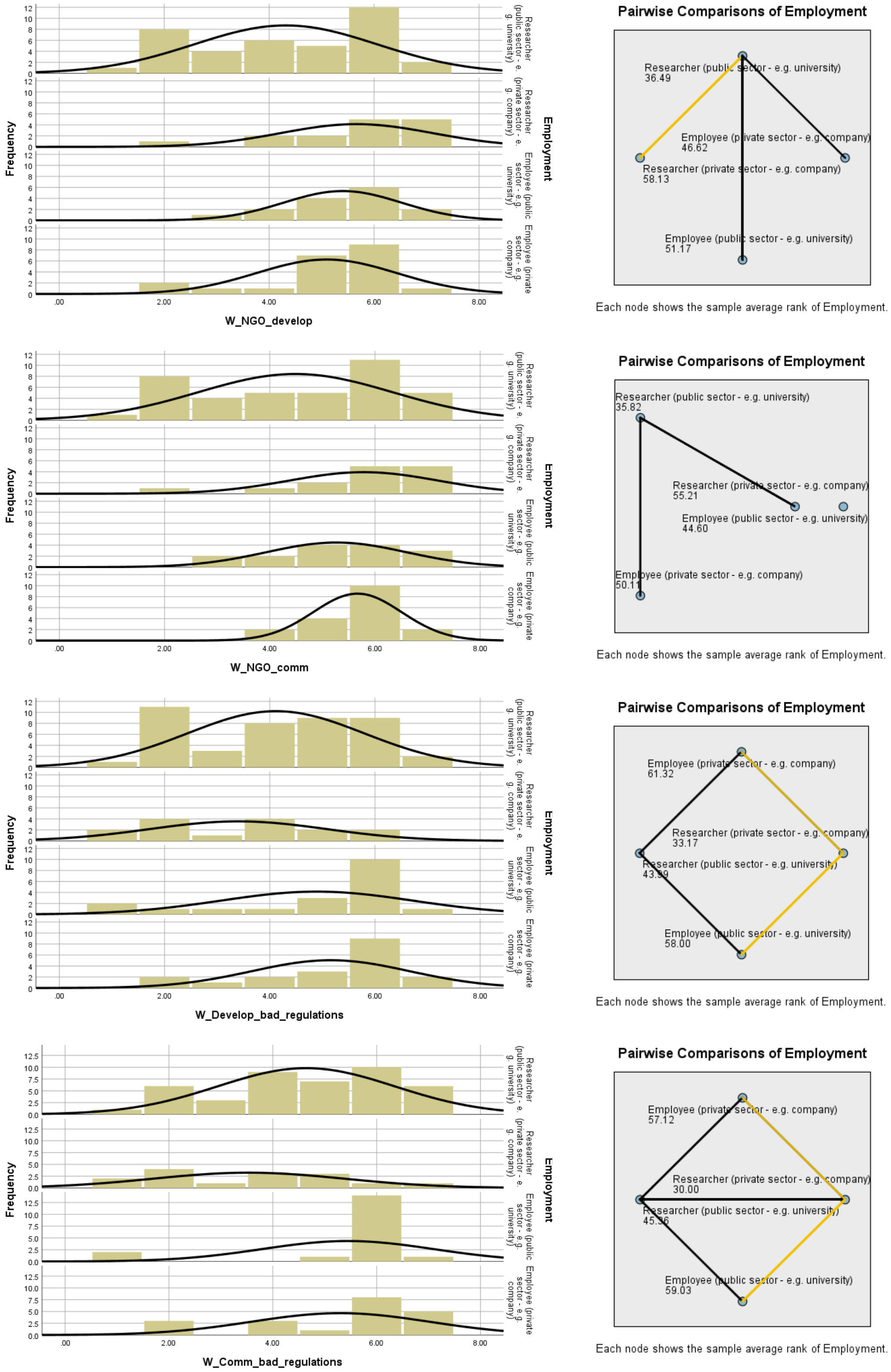


Figure 4 - Respondents' European region and significant survey questions.

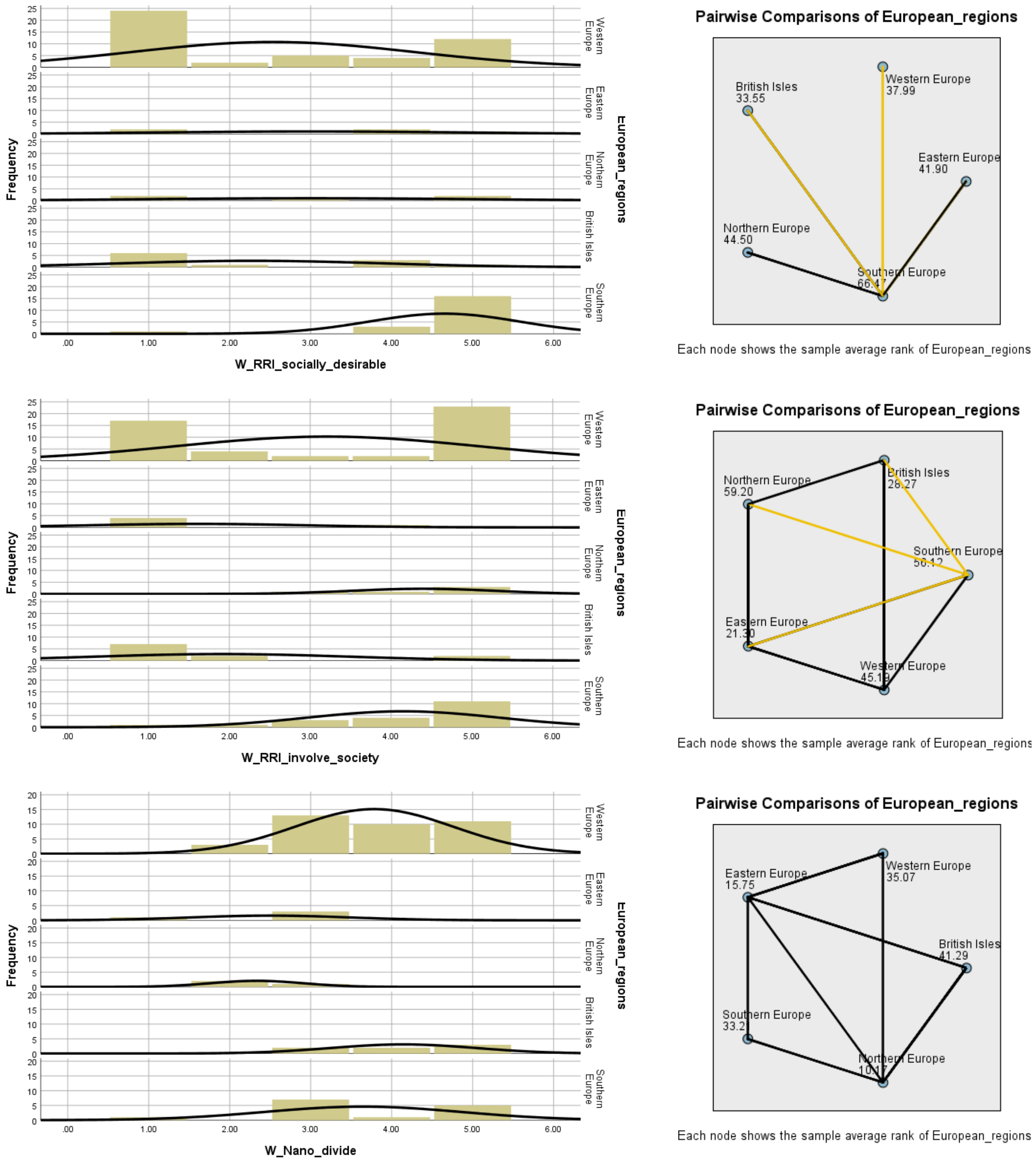


Figure 5 - Respondents' expertise and significant survey questions.

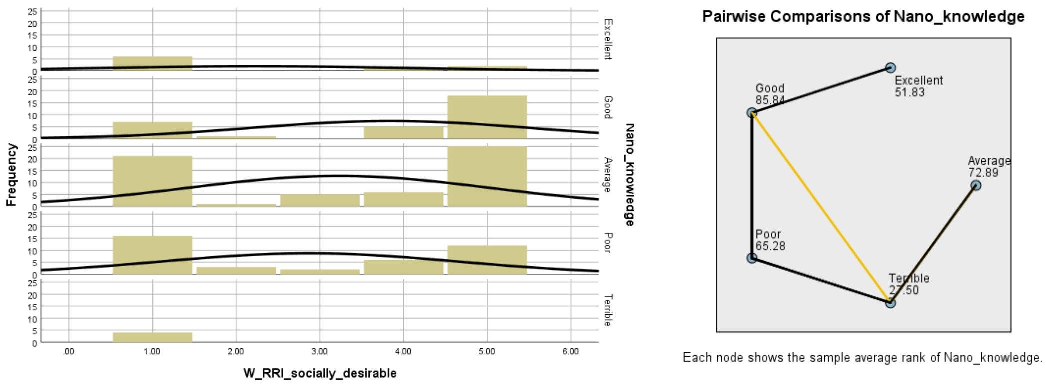
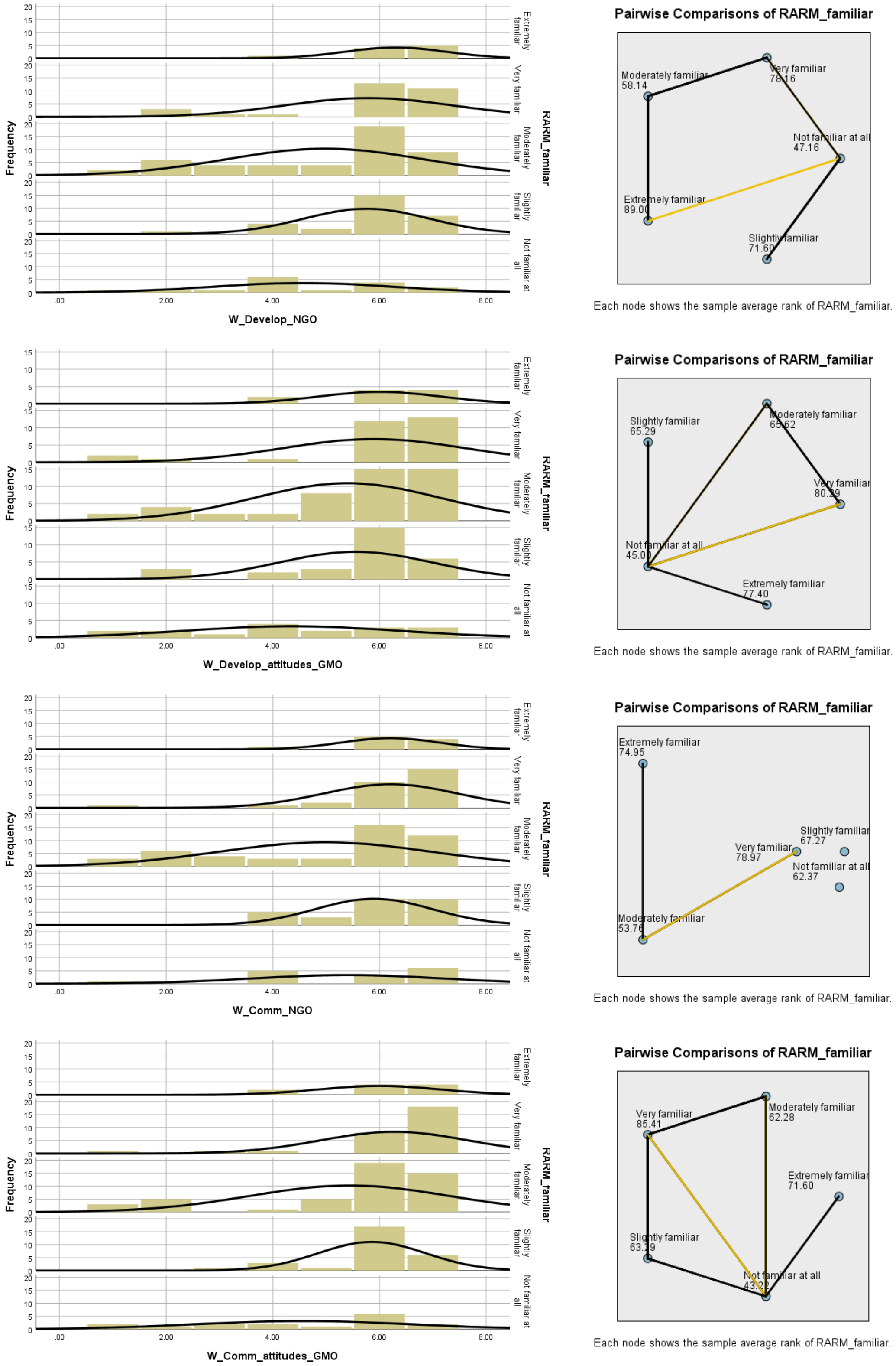


Figure 6 - Respondents' RARM familiarity and significant survey questions.



Appendix VI – Perception comparison among researchers and experts

Perceptions	Employment type		MW U value
	Researchers	Experts	
General blockage	3726	2944	1170**
Fundamentals	4122	2548	1558
Foreign blockage	4182	2488	1498
RRI expectations	4280	2390	1400

Note: Mean ranks are reported.
** Significance level at 0.05

Appendix VII – Influence of respondents' characteristics on clusters.

Variable	Cluster					χ^2-statistic
	CDC	GNB	LS	DA	RRIA	
Age	3.89 (1.08)	4.39 (0.95)	3.88 (1.04)	4.76 (1.02)	4.14 (1.29)	11.488**
European_regions	3.09 (1.81)	2.73 (1.72)	2.33 (1.59)	1.39 (1.15)	2.78 (1.93)	10.465**
Nano_knowledge	3.72 (0.75)	2.92 (0.97)	3.58 (0.83)	2.62 (0.90)	2.81 (0.78)	27.576**
RARM_familiar	4.06 (1.06)	2.66 (1.05)	3.75 (1.26)	2.90 (0.98)	3.19 (0.97)	27.875**
RRI_familiar	4.89 (0.32)	3.63 (1.15)	4.42 (0.88)	3.03 (1.24)	3.59 (1.12)	36.014**

Note: CDC = Confidence in the development and commercialization of agro-nanotechnologies; GNB = GMOs and NGOs barriers; LS = Legislation skepticism; DA = Definition acceptance; RRIA = RRI accordance.
** Significance ate 0.05 level.

Appendix VIII – Sample's characteristics that influence respondents' perceptions toward nanotechnologies