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Scenarios of nanotechnology development and usage in Turkey☆

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ABSTRACT

The analysis of future development of an emerging technology, e.g. nanotechnology, by experts has been criticized in the literature for the over-optimism they possess. A more balanced approach would be to take choices of the ordinary people and the effects of the environmental factors into consideration during this process. Prior work on willingness-to-buy for nanotechnology products has indicated that attitudes and beliefs of individuals may have a significant influence on the social acceptance process.

This study surveys the expectations of Turkish individuals and uses that information as an input to understand the possible developments in the use of products based on nanotechnology. Five different patterns emerging from the responses have been converted to 5 distinct scenarios suggesting various possible development paths for nanotechnology in Turkey.

A final scenario has also been formulated using the information on expected context of 2029. It foresees a future where nanotechnology and its applications will be significantly appreciated by the society and is expected to be used in almost all areas of the economy and industry. The survey participants, although reserving their doubts on the potential threats of nanotechnology on human health, will not be hesitant to use it. They also believe that, with increased public investment in the coming years, the utilization of this emerging technology will further be enhanced by 2029.

This study indicates that values of context and focus variables in 2009 and 2029 and foreseen changes from 2009 to 2029 may help companies in the resolution of three types of uncertainty concerning drivers of change, uncertainty about their evolution ("state" uncertainty), uncertainty about their impact on the competitive position of the firm ("effect" uncertainty), and uncertainty about the response viable to the firm ("response" uncertainty).

1. Introduction

Emerging technologies [3] of the 21st century are important for both public [4] and private sectors. They are often not acknowledged and not valued by the public [5], although their effects on the economic context are multiple, including opening up of new markets, increase or decrease of competition in an industry, location of production of goods/services, demand for factors of production such as labor and capital, implications for skills demand, consequences for wages and employment, and impact on the environment etc. [6].

Nanotechnology stands as a prominent example for these emerging technologies in this century [7]. Some economists hope that it would prove to be magic by 2025 [8]. The numbers from different sources seem to support this hope and may also give us a clue about the vitality of the concept. The National Science Foundation (NSF) of the USA has projected that the world market of nanotechnological products will reach 1 trillion USD in 2015. In a study completed in 2004, Lux Research

☆ Gidley [1] defines 4 types of futures in a study investigating the effect of the Steiner education system on the views and visions of the future of the youth. In this study she uses the term "probable future" that is a product of trend analysis and surveys and later Eckersley [2] employs the term "expected" instead of the "probable and possible" to define the type of the future that is about to happen depending on the views shared by the majority. In this paper, we will be using the term "expected scenarios" to emphasize the fact that scenarios are based on the assessments of survey questions by individuals revealing their expectations on the development and usage of nanotechnology in Turkey.

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has estimated a world market of 2.6 trillion USD for the year 2014 [9], whereas Tegart [10] reported an anticipated market size expected to reach 1 trillion USD by 2015. These statistics however can be problematic for the fact that in some studies even if the nanotechnology use of the product is limited and is just an input, researchers take the whole value of end product as the nanotechnological product, and in others they only consider the nanotechnology-used part [11].

It is hard to assess the real economic potential of nanotechnology [11,12], yet, it has already been applied in various fields, such as computer electronics, communication, energy production, medicine and food industry [13], probably requiring novel regulatory methodologies [14]. Economic and social promises and opportunities of nanotechnologies are very important for human beings considering the impact they would have on the public life in terms of quality and wealth creation.

On the other hand, nanotechnology possesses serious risks and dangers besides potentially huge benefits that are mentioned here. The nanomaterials that are incorporated into consumer products are claimed to be relatively inactive. Succeeding waves of nano-based products are expected to have far greater and more profound societal implications, especially as the worlds of nanotechnology, biotechnology, and information technology continue to converge and intersect with one another [15]. Concerns associated with nanotechnology are in line with problems expressed with the management of emerging technologies in general [16]. The issues such as "public perception" and "sustainable governance of nanotechnology" are important concepts and have to be analyzed carefully [17,18]. It is very likely that public perception of nanotechnology will be crucial for the realization of technological advances [19–21]. There are health and environmental concerns on future implications of nanotechnologies. These concerns may affect the willingness-to-buy behaviors of individuals [22,23,18].

There is certainly a need for gathering and assessing public opinion on nanotechnology and products incorporating nanotechnology, as individuals' considerations of the future are highly influenced by their identities and worldviews. The factors that influence the development of nanotechnology will inevitably shape the evolution of this technology and will determine its destiny [24]. Hopes can turn into a "miracle" or can be a "nightmare" for humanity. The state of it just being a "failure" is also among the possibilities. Hence, future research has been suggested to focus on better unraveling these relationships and on understanding their implications for future-oriented policy making [25,26].

There have been various applications of scenario construction for the development of emerging technologies and socio-technical systems which also include nanotechnology. Wiek et al. [27] employed an empirical qualitative system [28] to analyze many possibilities and utilized special software for producing and filtering the scenarios according to the pre-set criteria, with the perspectives of consistency, coherency and diversity. They presented a scenario study on the possible future developments of nanotechnology in Switzerland for the reference year 2020. Their analysis provided a typology of nanotechnological applications named "focus variables" and a set of "context variables" which are suggested to be relevant for the development of nanotechnology (see Section 3). Their conceptual framework produced five possible scenarios for the development of nanotechnology in Switzerland for five distinct market conditions.

The scenario construction methodology of the present study has been based on the answers to nanotechnology issues survey constructed using the focus variables and context variables reported in Wiek et al. [27]. The goal was to identify patterns in expectations of our respondents that would generate development scenarios of nanotechnology in Turkey. The Turkish government assessed nanotechnology as one of the 8 essential technologies in 2005 and research centers along with graduate programs at some universities were established [29]. This paper intends to assist the efforts of the Turkish government by developing futures scenarios of nanotechnology development and usage in Turkey based on a survey and cluster analysis.

The paper is structured as follows. Section 2 shows the literature review on nanotechnology futures. The scenario construction process is explained in the methodology section. The fourth section illustrates the anticipated changes in contexts of 2009 and 2029 and the expected scenarios of nanotechnology use in Turkey. Discussion and conclusions of the research are the final sections of this paper.

2. Nanotechnology futures and scenarios

Studies from various countries indicate different futures scenarios regarding nanotechnology. The effect of the emerging technologies in Finland by 2020 was explored based on a panel of experts [30] in 2004 with the result that nanotechnologies will still be under research in 2020, although there might already be some uses in the industry. Tegart [10] reported 3 scenarios for 2015 for APEC countries titled as; "nano-paradox", "green energy triggers collapse in energy markets", and "nanotech wins the war". The Danish nanotechnology foresight project [31] was also carried out with experts. In this study, time horizons for some nanotechnological products in certain areas are analyzed through a survey assessing the 32 statements under 7 headings:

- Nano-medicine and drug delivery
- Biocompatible materials
- Nano-sensors and nano-fluidics
- Plastic electronics
- Nano-optics and nano-photonics
- Nano-catalysis, hydrogen technology, etc.
- Nano-materials with new functional properties.

The statements were assessed by 133 experts. According to the responses, the periods in which those statements will become a reality were estimated. These periods are defined as "before 2010, 2011–2015, 2015–2020, and 2021–2025". The corresponding nanotechnological applications in 7 distinct areas are expected to be either in a *developing state* with a definite goal or prototype, or in a *practical application* stage, indicating a niche use of the product in a niche market, or in a *wide application* stage where the product is extensively used and gained significant acceptance from the public with a strong market position. Among the various results indicated concerning distinct sectors were:

- Practical application of intelligent systems in drug delivery systems which monitor the state of cells in the body and

report if, e.g., cancer or small blood clots arise, is estimated to realize in the period 2015–2025 and,
- Development of thermoelectric materials with radically improved properties for cooling and energy production, based on nano-sized structures is estimated to be realized between 2011 and 2015.

There are also studies done on nanotechnology in Asia. The results of the first Delphi-based survey on nanotechnology development [32] showed that for Taiwan:

- The nano-biomedicine domain has greater maturity;
- The maturation time of most techniques will be between 2010 and 2015;
- Nanocomposite material technique, nano-optoelectronic and optical communication, and nano-storage show relatively high competitiveness;
- Self-R&D and technology introduced from overseas are the major development methods in 2020.

Long term impact of the development of pervasive technologies on the environment was assessed by Dewick et al. [33]. They utilized a methodology based on long-wave theory and sector classification based on technological characteristics to analyze the effect of nanotechnology together with information technology and biotechnology. They suggested that nanotechnology will not have a significant effect on the agricultural sector before 2020, but will lead to significant improvements in the resource efficiency of agricultural output and thus on the economic growth. The result of a change on the society is an important issue. Ahlqvist [34] suggested that these key technologies will transform the society from bio-society to "fusion society" which will behave with a systemic nature — and will possess complex interactions between different technologies, the environment, the economy, and the society.

Scenarios can allow us to direct ourselves toward futures that we, as a society, believe ought to happen. A scenario planning template framework (Table 1, [35]) with two dimensions can be used by various stakeholders to discuss ethical matters pertaining to nanoscience and nanotechnology helping them to understand these complex interactions. Four scenarios given in Table 1 differ from each other, although most of their issues may overlap at some level. In order to deal with these potential issues in the present, different stakeholders need to realize that various values are at stake, regardless of the degree of impact nanoscience and nanotechnology might have.

Ideally, society's values should be established and questioned now, and then re-evaluated with the advent of new scientific breakthroughs. More explicitly, the agreed upon values, principles, and their respective regulations can help guide a responsible and ethics-aware nanoscience and nanotechnology development. Otherwise, this development occurs without awareness of any of these values, which presents us with a future in which nanoscience and nanotechnology are either banned all-together, or accepted at the expense of some of our previously-held values.

It is important to establish the mechanisms that will maintain and communicate best practices in this circumstance and to enhance the open communication channels between governments, industry and universities for setting the needed standards and regulations for responsible development of nanotechnology [36]. The study on regulatory frameworks that impact upon nanotechnology in Australia concluded that there is an emerging regulatory gap between the exciting commercial advances being made in this sector and community's expectations for regulatory safeguards and protections [37]. In another study – the Millennium Project – a two-round Delphi was conducted to identify and to rate important forms of nanotechnology-related environmental pollution and health hazards that could result from any military activities and to suggest military research that might reduce these problems [38].

Although, experts may have a realistic view of the situations, it is argued that the foresight exercises based on top experts may also cause over optimism [39] which is the case in the scenarios reported by Tegart [10], especially, the "green energy …" scenario "… By 2012 significant breakthroughs enabled car manufacturers to abandon petrol-fuelled vehicles and switch over to mass production of new fuel-efficient hydrogen-powered vehicles. Hydrogen fuel cells challenged conventional energy producers such as oil and natural gas power stations and by 2015 the demand for fossil fuel energy systems had collapsed".

A significant number of studies have identified that the public is wary of the potentially negative, unintended, inadvertent, and long-term consequences of new technologies [17–19]. Therefore, foresight exercises are suggested to include the views of the ordinary people with different types of knowledge and expertise as a reaction and possibly a needed balance to the over optimism of the experts [39]. As the literature is analyzed in depth, it is recognized that none of the above-mentioned studies reported demographic data on participants.

3. Methodology

In this section, the survey will be elaborated in detail. The survey, participants and transformation of data are the related subsections of the methodology.

Table 1
Scenario planning framework [35].

		Governance	
		Restrictive	Loose
Nanoscience and nanotechnology acceptance levellevels	High	*Undecided* Nanoscience and nanotechnology are socially accepted and embraced. Yet, the future is still uncertain.	*More of the same* Nanoscience and nanotechnology are widespread, but simply a technological evolution.
	Low	*No* People do not want it.	*Unfulfilled promises* The "breakthrough" never came. All nanoscience and nanotechnology brought were a trend and a few coatings.

Table 2
Variables used in the study.

Focus variables	Context variables
FV1: increase of agricultural efficiency	CV1: development potential
FV2: improvement of environmental quality	CV2: public awareness
FV3: increase of efficiency of energy systems	CV3: consumer demand
FV4: enhancement of nutritional quality	CV4: laws and regulations
FV5: increase of efficiency of information technology hardware	CV5: public investment
FV6: improvement of quality of medical/pharmaceutical products	CV6: profit potential
FV7: improvement of quality of cosmetics products	CV7: risk assessment
FV8: decrease of production costs	
FV9: improvement of textile properties	

3.1. Survey

The survey methodology has been used in this study. Nanotechnology issues survey held in 2009 targeted to get the personal assessment of several issues regarding nanotechnology and its applications and current and expected future context in Turkey by utilizing a Likert scale of 1–6. The data taken from several parts of this survey was the main resource for the analysis conducted.

There exist two types of variables used in this research, context variables and focus variables. As illustrated in Table 2, context variables are measured by the assessments for 2009 and 2029 with respect to 7 different criteria and focus variables are measured by expectations of the respondents for several nanotechnological applications in the related area of concern.[1] The responses regarding the focus variables aimed to reflect the expected time frames that a particular nanotechnological product will have a wide scale application by the society. Respective choices of time intervals were; 2010–2014, 2015–2019, 2020–2024, 2025–2029, 2030+, and Never. The choice of "Never" asserts that, the stated nanotechnological application would never be on the market for the use of consumers.

Other variables that enrich the content of the scenarios and assist in understanding the rationale of the events argued to exist in the future were aimed to measure the opinions of Turkish survey participants on the current position of Turkey in terms of capabilities and capacities in order to exploit the benefits of nanotechnological developments and on main constraints on occurrence that could possibly hinder such utilization and development process. They reflect the views of survey participants on Turkey's potential to be a part of this race and therefore, are included in our scenarios.

The scenario preparation framework in Appendix 1 integrates all those variables in one table and comprises the main source of information elaborated in the scenarios.

3.2. Participants

Data were collected by means of a web survey in Turkey in April 2009. Participants were from a diverse panel of Internet users. Students from Yeditepe University were informed and encouraged to this web-based survey. There were also other respondents who were not part of the university population. The sample comprised of Turkish individuals – undergraduate, MBA and PhD students of Yeditepe University – and individuals aged above 40. A convenience sample[2] of 324 respondents participated in our survey. 99 fully completed surveys were used in the analysis. We have a 30.5% response rate for this particular survey.

According to the results in Table 3, out of the 99 respondents, 78.5% are under the age of 40. There were 30 female and 68 male respondents. The majority of the sample belongs to the age group 20–29 making up for 47%, followed by the 30–39 with almost 30% of all respondents.

Table 4 illustrates that, 9.1% of the samples are from government (public) institutions, 51.02% come from private for profit, 4.0% from third sector (foundations, associations) and finally 35.7% from university.

Table 5 shows the cross tabulation of descriptive data; approximately 45% of the samples are aged between 20 and 39 and work in the private sector, followed by respondents from the university that are in the same age group with a 23% of appearance. The self-assessment of expertise section of our questionnaire indicated that 38.7% of our sample is at least familiar with the concept of nanotechnology. The majority of the sample (52%) however reported a casually acquainted knowledge on nanotechnology with 86% of it belonging to the age groups including 20 to 39.

3.3. Transformation of data

Wiek et al. [27] have used year 2020 as the reference year in their research. Nano-technological applications in various sectors of focus variables have been viewed to be "on the market" if the use of that product will be before 2020 and "not on the market" if it occurs after the year 2020. The current study however asked participants about possible time of occurrences of the selected nanotechnological applications by determining specific time intervals which they can chose from. Thus, focus variables which reveal those expectations, can be illustrated in detail (Appendix 3). On the other hand, context variables of this study have been measured with the same logic used by the Swiss study. Nevertheless, the basic difference of our work compared to Wiek et al. [27] is that the results are based on the expectations of the respondents instead of the analysis of possible alternative outcomes from a computer

[1] The definitions of the focus and context variables are presented in Appendices 2 and 2a. Those definitions have been taken from the work of Wiek et al. [27] and presented in the survey to the respondents.

[2] Souza et al. [40] analyzed convenience sampling and its relation with the population. Their study suggests that it can be shown that convenience sampling can represent the population.

Table 3
Age — gender distribution of the participants (N = 98, missing = 1).

Gender	Age					
	<20	20–29	30–39	40–49	50–59	60+
Female	2	18	7	2	1	0
Male	0	28	22	9	7	2
Total	2	46	29	11	8	2

Table 4
Main sector of activity — degree of expertise on nanotechnology distribution of the participants (N = 99).

Main sector of activity	Total	1 unfamiliar	2 casually acquainted	3 familiar	4 knowledgeable	5 Expert
Government/public	9	0	2	4	2	1
Private for profit	51	4	34	11	1	1
Third sector	4	0	1	3	0	0
University	35	5	16	10	3	1
Total	99	9	53	28	6	3

program. Cluster analysis was instrumental in the analysis of the survey results.

Cluster analysis is an exploratory data analysis tool for organizing observed data (people, things, events, brands, companies) into meaningful taxonomies, groups, or clusters, based on combinations of independent variables which maximizes the similarity of cases within each cluster and at the same time maximizing the dissimilarity between groups that are initially unknown [41]. Searching the data for discovering a structure of grouping is important. In this respect, elements within a cluster have a high degree of natural association among themselves whereas clusters are relatively distinct from one another. Cluster analysis however reduces the number of observations or cases by grouping them into a smaller set of clusters [41].

Necessary transformations have been made in order to form the clusters that are used for the generation of expected scenarios of the current study. The initial clusters that are formed using SPSS software have been modified and re-clustered according to pre-set criteria.[3] The unique characteristics of those final clusters have been utilized as inputs for the scenarios that are generated.

4. Results

The changes in context variables from 2009 to 2029 and expected scenarios for nanotechnological development for the reference year 2020 are given in this section together with the final scenario for the year 2029, covering a 20-year time frame (2009–2029).

4.1. Change in context 2009 vs. 2029

Table 6 gives the mean values of all the respondents for the context variables for 2009 and 2029 as a total and Table 7 illustrates the shift in the expectations in each cluster for the context variables from 2009 to 2029.

Context variables are measured by using a Likert scale from 1 to 6. The variables measuring the demand for "economically priced nano-technological products", "environmentally friendly nanotechnological products" and "nano-free products" were measured as a sum totaled to 100 and participants were asked to divide this sum among them indicating the expectations in the demand of each product. In this study, the year 2029 is selected to analyze the 20-year time frame. Although, the respondents in each cluster differ from one another in terms of their expectations, our sample converges to a common route on their assessment of the future, that is the context of 2029.

Results in Table 6 indicate that development potential of nanotechnology is expected by the survey participants to increase in 2029 with the same level of awareness for nanotechnological products and applications from the public. The government is anticipated to have a more supportive approach by increasing public investment and by securing a liberal stance in terms of laws and regulations. Participants expect the same level of risk on nanotechnology and its applications during this period.

Private sector is expected to intervene more in this area due to high profit potential in 2009 and which is also expected to be higher in 2029. As far as the choice for the nanotechnological applications are concerned, environmental friendly nanotechnological products have a high level of acceptance followed by economical nano-products. Yet, approximately one third of the sample opposes the use of nanotechnology and will be demanding nano-free products.

Overall, analysis on the change of context suggests that "all the different contexts determined by clusters, converge to a final setting where, there is high development potential, neutral public awareness, almost evenly distributed consumer demand with the lead of environmentally friendly nano-products, more laws and regulations, high profit potential and public investments and a medium risk assessment by the public".

4.2. Nanotechnology scenarios for 2020

The respondents of nanotechnology issues survey have been partitioned to 5 distinct groups (clusters) with the help of the SPSS software. Those clusters are the distinct patterns that emerged from the responses to the survey for focus variables and also taking into account the expected changes

[3] Interested readers may contact the authors for details of the conversion processes.

Table 5
Cross tabulation results of the Turkish participants.

Main sector of activity	Gender		Age					
	Female	Male	<20	20–29	30–39	40–49	50–59	60+
Government/public	2	7	0	3	3	2	1	0
Private for profit	11	39	0	23	21	4	2	0
Third sector (assoc., found.)	0	4	0	2	0	0	2	0
University	17	18	1	18	5	5	3	2
Total	30	68	1	46	29	11	8	2
Degree of expertise on nanotechnology	Female	Male	<20	20–29	30–39	40–49	50–59	60+
1 = unfamiliar	3	6	0	6	2	1	0	0
2 = casually acquainted	16	35	0	28	16	4	2	1
3 = familiar	8	20	1	12	9	0	6	0
4 = knowledgeable	2	5	0	0	1	4	0	1
5 = expert	1	2	0	0	1	2	0	0
Total	30	68	1	46	29	11	8	2

in context variables. These clusters were our basic source for generating the scenarios of nanotechnology development and usage in Turkey. The scenario preparation table in Appendix 1 illustrates future projections of the scenarios of the Turkish sample. Respective scenarios generated from the survey are given in the following sections. Based on the number of products anticipated to be on the market by 2020, the first scenario is titled as “nano-averse” scenario, the second “go nano”, the third “limited nano”, the fourth “low nano” and the fifth “incapable to nano”. There is one more that was generated to capture the changes in the context from 2009 to 2029. The “Nanotech Future” scenario is the final scenario reflecting the expected nanotechnology usage development in Turkey for the year 2029.

As expressed before, instead of stating the conceptual possibilities that may have or may not have occurred, this study has focused on the expectations of a Turkish sample on nanotechnology through the survey methodology. Therefore, once the clusters are determined, the context characteristics of each cluster and their respective perceptions for the realization of nanotechnological applications with the corresponding factors that have influence on them, have been analyzed and shown in Appendix 1. The *current position* of Turkey in terms of capabilities to seize the opportunities of nanotechnology and the *constraints on occurrence* constitute those factors. A quick glance at the table in the same appendix indicates that scientific and technological capabilities and innovative capacities of Turkey are expected to be lagging, whereas production capabilities regarded as leading according to the assessments of the survey participants.

Table 6
Comparison of the context variables for the years 2009 vs. 2029 in Turkey.

Context variables	Mean value 2009	Mean value 2029
Development potential	3.28	4.17
Public awareness	3.42	3.53
Econ. priced nano-products	36.82	31.46
Environ. friend. nano-prod.	41.01	44.14
Nano-free products	21.36	24.34
Laws & regulations	1.64	2.17
Public investment	2.67	4.13
Profit potential	3.85	4.33
Risk assessment	3.43	3.55

Finally, the major constraint for the occurrence of all those nanotechnological applications has been confirmed as the funding problem. Therefore, unavailability of financial resources devoted to research and development is anticipated as the biggest constraint on the predicted development of nanotechnology in Turkey in our scenarios.

4.2.1. Scenario # 1 — “nano-averse”

This scenario foresees an environment where there exists not a single nanotechnological product on the market. We named it as “nano-averse” since; the main factor that differentiates it from others is the perception of risk and its effect both on the demand for nanotechnological applications and on the development of nanotechnology in general. The majority of respondents of this group are generally risk averse. They believe that profit potential of this new technology is high, but they also reserve their doubts on its potential for development. Possible long term consequences of this emerging technology have been viewed as dangerous and harmful for the general public and therefore the risk assessment is considered to be high.

From the business perspective, if there is a high profit potential anticipated in an area, solid investments can be expected. Nevertheless, high risk assessment and high consumers' demand to the nano-free products inevitably cause private institutions to hesitate for those necessary investments. According to this “nano-averse” group, economic impacts of this technology are not viable. This causes a low public investment by the government as well.

The scientific, technological and innovative capacities of Turkey will be the major drawbacks for the development of nanotechnology. High productive capacity is a plus but; facts stated above restrain the positive progress. In terms of laws and regulations, there are no restrictions that prohibit the usage of nanotechnology. Expectations for a possible occurrence of nano-accidents and nano-crimes are also among the reasons of high risk assessments of this scenario. The media through its channels of communication affects public debates and discussions negatively with a broad coverage for the possible adverse consequences and hence, is an influential factor in spreading the negative attitudes toward nanotechnology in general.

According to this scenario, public and private institutions are reluctant to invest in nanotechnology due to the high risk

Table 7
Changes in context variables 2009 vs. 2029 for different scenarios.[a]

Context variable	Cluster no.	Scenario name	Value 2009	Value 2029
Development potential	1	Nano-averse	3.23	4.08
Public awareness	1	"	2.38	3.15
Econ. priced nano-prod.	1	"	38.85	26.92
Envir. friend. nano-prod.	1	"	27.31	43.46
Nano-free products	1	"	34.62	30.38
Laws & regulations	1	"	Liberal	Reg. food. & tex
Public investment	1	"	2.92	4.38
Profit potential	1	"	4.15	4.38
Risk assessment	1	"	4.69	3.92
Development potential	2	Low nano	2.57	4.09
Public awareness	2	"	3.96	3.30
Econ. priced nano-prod.	2	"	30.65	30.00
Envir. friend. nano-prod.	2	"	48.91	45.87
Nano-free products	2	"	16.52	23.48
Laws & regulations	2	"	Liberal	Reg. food. & tex
Public investment	2	"	2.17	4.13
Profit potential	2	"	2.17	4.13
Risk assessment	2	"	2.70	3.43
Development potential	3	Go nano	2.50	3.94
Public awareness	3	"	3.83	3.61
Econ. priced nano-prod.	3	"	41.11	37.50
Envir. friend. nano-prod.	3	"	45.83	45.00
Nano-free products	3	"	13.06	17.50
Laws & regulations	3	"	Liberal	Reg. food. & tex
Public investment	3	"	1.83	3.56
Profit potential	3	"	4.78	4.67
Risk assessment	3	"	2.67	3.11
Development potential	4	Limited nano	4.37	4.15
Public awareness	4	"	3.19	3.67
Econ. priced nano-prod.	4	"	36.11	31.11
Envir. friend. nano-prod.	4	"	35.74	40.37
Nano-free products	4	"	28.15	28.52
Laws & regulations	4	"	Liberal	Reg. for both
Public investment	4	"	3.00	4.26
Profit potential	4	"	3.93	4.07
Risk assessment	4	"	3.74	3.59
Development potential	5	Incapable to nano	3.39	4.61
Public awareness	5	"	3.44	3.78
Econ. priced nano-prod.	5	"	40.00	31.11
Envir. friend. nano-prod.	5	"	43.89	47.22
Nano-free products	5	"	16.11	21.67
Laws & regulations	5	"	Reg. food. & tex.	Reg. food. & tex
Public investment	5	"	3.44	4.33
Profit potential	5	"	4.72	4.61
Risk assessment	5	"	3.78	3.78

[a] The context variables such as development potential, public investment and profit potential take the value labels "low–high" depending on their numerical values. The variables public awareness and risk assessment take the value labels "low–medium–high" and "risk averse–neutral–risk tolerant" with respect to their numerical values, respectively. They are not shown in the table.

and low development potentials. Considering the fact that there are already many products that exist on the market, this scenario is unrealistic.

4.2.2. Scenario # 2 — "go nano"

"Go nano" scenario reflects the best possible case in terms of the range of products that is expected to be on the market before the year 2020. There is a low development potential and public investment, as it occurred to be a common case for all the clusters. However, high profit potential of this technology promises new opportunities and can be argued to be the main reason for most of the products that appear on the market. It is likely that, a high profit potential enables the private sector to invest in nanotechnology in an environment where public acceptance is neutral for such new technologies and products and is medium in terms of the risks possessed by them. The government does not fund any of the projects yet, it also does not restrict the potential development by any laws or regulations or any other kinds of legal barriers. Expected consumer demand is high for both economically priced and environmentally friendly nano-products.

Funding is the major constraint on the occurrence of a possible nanotechnology revolution according to this scenario. The initial products that appear on the market will be in particular areas such as; textile, medical and pharmaceutical industries, improvements in energy efficiency, and lowering production costs. Although, there are many products on the market, the areas of nutritional quality and environmental quality seem to have no applications. The limited funding by the institutions and especially from public side together with the limited scientific and technological capability may have caused developments and innovations to arise in the areas, where risk is low, products can easily be marketed and return on investment is quick. This inevitably enlarges the range of products available to the public. Expectations on this scenario are optimistic and even though the public side is reluctant to invest, the private side covers for both. Therefore, the development of nanotechnology will continue without any significant obstacle that seems to interrupt this progress.

4.2.3. Scenario # 3 — "limited nano"

The "limited nano" scenario is complicated in the sense that although development and profit potentials are high, still there is a limited range of products compared to the "go nano" scenario. The environment characterized by public awareness and risk assessment is neutral and the government does not pose any significant restrictions on the development of the technology through any kind of laws or regulations. The nanotechnological applications on the market are generally in those sectors that have indirect contact with consumers. Applications for decreasing production costs, increasing agricultural efficiency and also the ones used in medical and pharma to improve the quality of life are not expected to materialize.

This scenario views the current position of the country more capable in terms of the scientific, technological, innovative and commercial capabilities and capacities. However, major constraints such as funding, force the limited capacities and capabilities of private sector and inevitably cause them to focus only on the product developments in those sectors that are more profitable or less risky. The difference with respect to the "go nano" scenario is the fact that, despite the low risk assessments, possible occurrence of nano-accidents in some sectors is still an expected fact and can limit the investment will of the public sector. This can also restrict the demand only to those sectors, where there is limited direct contact with the nanotechnology or at least hard to identify.

4.2.4. Scenario # 4 — "low nano"

This scenario describes a situation where, neither public nor private sector is eager to invest in nanotechnology. The reason for this may depend on the fact that, both the development and the profit potential of this technology are viewed as low. There is no economic viability of investing and therefore, funding level is low. Still, there exist some products on the market with a very limited appearance and focusing on specific sectors such as cosmetics and IT hardware due to the innovative nature of those particular sectors. The main difference of this scenario with the "Limited Nano" scenario is the nature of the products on the market. There is more contact by consumers to the nanotechnological applications in this scenario compared to the products stated in that scenario. Applications to decrease production costs or to improve textile properties constitute the product scale in "low nano" scenario. Considering the marketability of those products and the return on investment criteria, this particular scenario expects that only products that satisfy these conditions will exist on the market.

The demand for environmentally friendly nano-products is high compared to others. Public awareness is neutral and risk assessment is medium. Although, any kind of a prominent risk or an accident is not expected and considering the fact that the stated expertise level of this group is relatively high to others, lack of investment to this technology merely depends on the economic reasons and may result in the limited appearance of the products.

4.2.5. Scenario # 5 — "incapable to nano"

This scenario is very close to "nano-averse" scenario in terms of product range appearing on the market. The nanotechnological applications exist only in the area of agricultural efficiency. Public investment and development potential are low. Public awareness is neutral and risk assessment is medium. Surprisingly, profit potential is high with 100% of the respondents in this group think in the same direction. Demand for nanotechnology-free products is lower than the demand for environmentally-friendly and economically-priced nanotechnological products. As far as the private sector is concerned, there is a positive investment environment with high profit and low risk and only some legal restrictions applied in the area of food and textiles.

Respondents in this group view that scientific and technological capabilities and innovative capacities are low in order to exploit the potential benefits of this technology, yet, they believe in the possible commercialization of nanotechnological products on the market.

The role of education and inexistence of a skill base are strongly emphasized and are regarded as the major constraints together with the funding on a sustainable technological progress. Educated and capable personnel are needed in order to support the scientific and technological capabilities of the country. Moreover, the key personnel such as; scientific researchers who will innovate and test the products and government officials who will understand and manage the sustainable governance of this technology and illuminate the public to the potential risks and strategy makers in both public and private sectors to oversee the management of emerging technologies are not supplied enough according to this scenario. This seems to be the main reason for the absence of nanotechnological applications on the market. Thus, although there is a profit potential and medium risk, these incapabilities hinder the development of nanotechnology.

4.2.6. Development scenario of nanotechnology for 2029 — "nanotech-future"

Results presented in previous sections enhance the generation of a final scenario for nanotechnological development in Turkey, this time with a 20-year time horizon, for the year 2029. The expected change of context from 2009 to 2029 illustrated in Table 2 and the expected time of occurrences for each focus variable (Appendices 3a, 3b) have been used as the input to form this scenario. Responses of individuals reflect their expectations and thereby their images of the future. Fig. 1 depicts this scenario in a form borrowed from Wiek et al. [27].

According to this scenario, institutions will become more expert in terms of identifying the potential threats and with increased necessary regulative measures; they will also be more capable in management of such processes and will enhance the sustainable development of emerging technologies. Society's agreement on this fact has increased the social trust in those institutions and in professionals working for them who are assumed to have the necessary training and education. Public awareness is not risk averse anymore, but not risk tolerant either. Even the most risk averse groups are assured that the development process is well managed and there will be no accidents or threats expected in the future that can potentially harm human beings and damage their environments significantly. And in case of such an accident, related institutions will take the best protective measures and will inform society about the possible dangers of the situation immediately.

High profit potential has attracted many companies and has significantly influenced the development and innovation processes. Governments prioritized this emerging technology in their strategic plans for the future and a competition among the countries has begun. Inevitably, the Turkish government assumed its role in this race and therefore a prominent increase in funds and research activities through increased public investments has occurred. With all the technical, social and economic capabilities improved in the future, nanotechnology has reached its maximum development potential that is possible.

Initial products that are marketed were in the area of information technology hardware and textile applications, where there has always been a consistent demand. Increase of efficiency for hardware and new properties of textiles increased quality of life and were adopted easily. Developments in the medical and pharmaceutical industries together with the applications for sustaining efficiency and decreasing the production costs took place in the second wave of this development. Products sustaining; increase in agricultural efficiency, improvements in environmental quality, increase in energy efficiency, improvements in cosmetics were on the market around 2020s on average. Applications for nutritional quality however were found to be more risky with insignificant demand and therefore attracted less attention with the average time of occurrence of 2022 (see Appendix 3).[4]

This scenario generally expects an optimist pace of growth for nanotechnology with most of the potential applications taking their place on the shelves before 2029. Any major accident that will influence this growth is not expected, but, it also does not argue that the risk is minimal.

5. Discussion

The present study tries to reveal the issues effecting the development of nanotechnology in Turkey. Scenarios are formed based on cluster analysis of the survey data. It tries to reflect the expectations of Turkish participants on development and usage of nanotechnology in Turkey in scenario format. Predictions of Turkish participants for possible time of occurrences of the nanotechnological applications in pre-determined strategic areas are revealed. As potential future consumers of those products, their views may be useful in the public and private decision making processes.

Nanotechnological applications targeted to improve environmental quality and to enhance nutritional quality are not expected to exist in any of the scenarios for the year 2020. A possible explanation to this would be that the initial products expected to appear on the market will be the ones that are less risky and more profitable. In an environment where public investment is anticipated to be low in all scenarios, burden falls on the shoulders of the private sector. This issue influences not only the nature of those products marketed but also the investment decisions. Therefore, it is not a surprise that early applications expected to be on the market will be for increasing the efficiency of information technology hardware and for improvement of textile properties with an expected average time of occurrence in 2018 and 2019 respectively (Appendix 3).

According to the results of the nanotechnology issues survey, Turkey is claimed to have insufficient resources in terms of scientific and technological capabilities for the sustainable development of nanotechnology. This has been illustrated in Appendix 1 and is a common case for all scenarios stated in this study. Funding is expressed as another problem by four of the five scenarios except the "nano-averse" scenario which suggests economic viability as the major constraint followed by funding problem. Social and ethical acceptability has been identified as the least important constraint in the development process. This result is in line with risk assessment and public awareness level of scenarios where the survey participants seem to be neutral in general. Therefore, it can be argued that sample population is not aware of the possible adverse consequences of nanotechnology such as nano-accidents or nano-crimes yet. As the self-reported expertise on nanotechnology of two-thirds of the participants is either unfamiliar or casually acquainted, it is likely that the uninformed public would be possibly unaware of the potential threats and is inadvertent of the consequences as suggested in the literature [15,17–19,21].

Assessment of the changing context is also an important aspect of this study. Table 6 illustrates the mean values for context variables for the reference years 2009 and 2029. Expectations regarding the variables of context favor a possible development of nanotechnology usage as almost all values either increase or stay at the same level. Results indicate that development potential and public investment are expected to increase in 2029 whereas profit potential, risk assessment and public awareness are anticipated to stay at the same level. Legal environment is expected to be supportive with a liberal stance as far as this emerging technology is concerned. The conditions in Turkey are expected to improve for the sustainable development of nanotechnology and its applications in various sectors. The "Nanotech Future" scenario predicts that almost all nanotechnological applications[5] are anticipated to be on the market by the year 2029. It is a very strong statement and it may or may not hold but, the main issue here is that images and expectations of the future consumers regarding those nanotechnological applications are indicated with the help of this study. As being an important stakeholder in this development process, a careful analysis of those views and attitudes can improve policy making process in the public and private sectors.

The values of context and focus variables in 2009 and 2029 and the foreseen changes from 2009 to 2029 may also help companies in the resolution of three types of uncertainty concerning drivers of change; uncertainty about their evolution ("state" uncertainty), uncertainty about their impact on

[4] Various methodologies have been used to calculate the expected time of occurrences of the pre-determined nanotechnological applications and finally the average of those calculations are taken as the main statistic to reduce any form of bias. Interested readers may contact the authors for details.

[5] While not comprehensive, the inventory compiled by NanoTechProject [43] gives the best available look at the 1600+ manufacturer-identified nanotechnology-based consumer products introduced to the market as of January 2014.

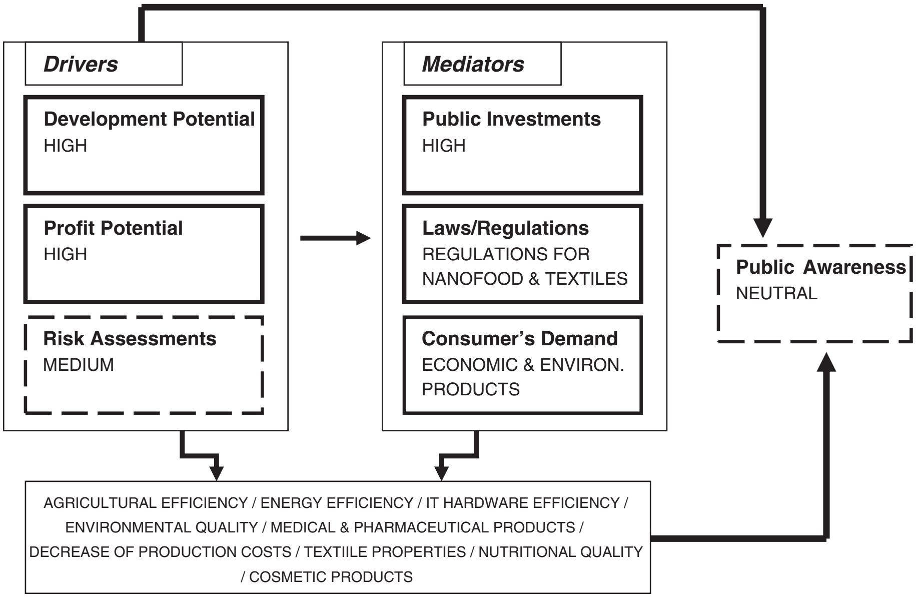

Fig. 1. The graphical representation of the development scenario of nanotechnology for 2029 "nanotech — future".[6]

the competitive position of the firm ("effect" uncertainty), and uncertainty about the response viable to the firm ("response" uncertainty) [42].

6. Conclusion

Wiek et al. [27] had reported 5 scenarios using pre-set criteria considering all possible combinations that are plausible and consistent by using computer software (probable futures scenarios of nanotechnology). The current study has analyzed the possibility of occurrence of those variables using the responses of a group of Turkish individuals. Corresponding results can therefore, be viewed as "expected futures scenarios of nanotechnology development and usage" in Turkey.

Using the same variables from a prior study to generate nanotechnology scenarios is intended to serve the purpose of comparison for future research efforts. There existed future projections for focus variables decided by specific time intervals and also for context variables for the year 2009 and 2029 determined by the answers of Turkish respondents' assessments. These data enabled us to analyze focus variables in depth from different angles.

Five distinct patterns have emerged from the responses of Turkish sample. These patterns determined by using the explained methodology have been converted to 5 distinct scenarios in order to put forward stories of the possible development of nanotechnology usage in Turkey. According to the final scenario, the participants foresee a future where nanotechnology and its applications will significantly be appreciated and will be used in almost all the areas of the industry by the year 2029. The respondents with their doubts on the potential threats of nanotechnology on human health will not be hesitant to use it. Increased public investment is expected to enhance the utilization of this emerging technology by 2029. The attitudes of survey participants regarding the nanotechnological development are positive with reservations on the potential risks and threats.

This study has been beneficial in revealing the expected development paths of nanotechnology usage in Turkey. Yet, it possesses certain limitations. Sample size of 99 completed surveys does not reflect the Turkish society as a whole. The nature of the sample can also be problematic in assessing the contexts of 2009 and 2029. Using a target group with a higher average age may give us different results since their stance to emerging technologies may somewhat be different than the younger ones.

Finally, limited public knowledge about nanotechnology, which has been shown in the assessment of degree of expertise on nanotechnology of the participants, may give different results than if the survey were answered by experts who are expected to analyze the possible opportunities and threats more accurately. The nano-toxicity is a major issue being among those threats. Increase of public awareness on health issues may concern the development of nanotechnology development and usage which can be analyzed as a future work. A Delphi study covering a wider range of stakeholders such as government officials, non-governmental organizations, professionals working in those sectors and general public seem to be more relevant.

This is the first study that tries to highlight the expected development of nanotechnology usage in Turkey from the perspective of a group of ordinary citizens who comprise an important part of possible stakeholders in the environment. The results may serve as a guide to companies developing and employing nanotechnology, as expectations of members of the Turkish society may determine their attitudes toward this technology as future users of those nanotechnological applications.

[6] The frames of the boxes of the context variables are drawn according to their individual values, ––––––– low values, – – – – – medium (neutral, liberal) –––––– high values.

Appendix 1. Scenario preparation table for 2020.

Variables	Definitions	Cluster (1) N = 13	Cluster (5) N = 18	Cluster (2) N = 23	Cluster (4) N = 27	Cluster (3) N = 18
Focus variables	Market presence by 2020	Nano-averse	Incapable to nano	Low nano	Limited nano	Go nano
FV1	Applications to increase agricultural efficiency	Not on the market	On the market	Not on the market	On the market	On the market
FV2	Applications to improve environmental quality	Not on the market	Not on the market	Not on the market	Not on the market	Not on the market
FV3	Applications to increase efficiency of energy systems	Not on the market	Not on the market	Not on the market	Not on the market	On the market
FV4	Applications to enhance nutritional quality	Not on the market	Not on the market	Not on the market	Not on the market	Not on the market
FV5	Applications to increase efficiency of it hardware	Not on the market	Not on the market	On the market	Not on the market	On the market
FV6	Applications to improve quality of medical & pharma	Not on the market	Not on the market	Not on the market	On the market	On the market
FV7	Applications to improve cosmetic products	Not on the market	Not on the market	On the market	Not on the market	Not on the market
FV8	Applications to decrease production costs	Not on the market	Not on the market	Not on the market	On the market	On the market
FV9	Applications to improve textile properties	Not on the market	Not on the market	Not on the market	On the market	On the market
Context variables 2009						
CV1	Development potential	3.23	3.39	2.57	4.37	2.50
CV2	Public awareness	2.38	3.44	3.96	3.19	3.83
CV3	Consumer's demand					
	High for — economically priced products	Eco. products	Eco. products		Eco. products	Eco. products
	High for — environmentally friendly products		Env. products	Env. products		Env. products
	High for — nanotechnology — free products	Nano-free products			Nano-free products	
CV4	Laws and regulations	Liberal (76.9%)	Reg. for nanofood & text. (88.9%)	Liberal (60.9%)	Liberal (59.3%)	Liberal (99.4%)
CV5	Public investment	2.92	3.44	2.17	3.00	1.83
CV6	Profit potential	4.15	4.72	2.17	3.93	4.78
CV7	Risk assessment	4.69	3.78	2.70	3.74	2.67
Current position						
	Scientific & technological capability	Lag — scientific	Lag — scientific	Lag — scientific	Lag — scientific	Lag — scientific
	Innovation capacity	Lag — innovation	Lag — innovation		Lead — innovation	
	Production capability or service delivery	Lead — prod. cap.		Lead — prod. cap.		Lead — prod. cap.
	Exploitation & commercialization potential		Lead — exploit…			
Constraints on occurrence						
	Social/ethical acceptability	7	7	7	7	7
	Technological feasibility	3	4	6	5	2
	Industrial/commercial	5	5	3	6	6
	Funding	2	1. Major constraint	1. Major constraint	1. Major constraint	1. Major constraint
	Economic viability	1. Major constraint	3	1. Major constraint	3	4
	Regulatory/policy/standards	5	5	4	2	5
	Education/skill base	4	2	5	3	2

Appendix 2a. The definitions of focus variables.

Focus variables	Title	Definition
FV 1	Increase of agricultural efficiency	Nanotechnological applications that improve the agricultural output per area and/or time and/or input
FV 2	Improvement of environmental quality	Nanotechnological applications that actively clean polluted air, water and/or soil, are beneficial for eco-system process and structures
FV 3	Increase of efficiency of energy systems	Nanotechnological applications that improve the ratio between produced energy and resource input due to improved production, storage and conduction of energy
FV 4	Enhancement of nutritional quality	Nanotechnological applications that modify the characteristics of food in order to satisfy nutritional demands of the consumer, or increase food safety
FV 5	Increase of efficiency of information technology hardware	Nanotechnological applications that increase speed of data processing, storage capacity and information transmission, or miniaturize hardware devices
FV 6	Improvement of the quality of medical, pharmaceutical and cosmetic products	Nanotechnological applications that improve and simplify diagnostics, treatment and healing of diseases, or increase efficiency of drug delivery and/or tolerance of implants, or improve the quality of the personal hygiene
FV7	Decrease of production costs	Nanotechnological applications that lead to cost reduction in the production process
FV 8	Improvement of textile properties	Nanotechnological applications that enable new functions and properties of textiles

Appendix 2b. The definitions of context variables.

Context variables	Title	Definition
CV 1	Development potential	Global know-how and infrastructure for R&D of nanotechnology
CV 2	Public awareness	Turkish population's awareness of nanotechnology, including understanding, perception of risks/ benefits, and acceptance
CV 3	Consumer's demand	Turkish consumer's demand and choices of nanotechnology, including habits, preferences, and values
CV 4	Laws and regulations	The legal framework for the development and use of nanotechnology in Turkey, including laws, decrees, and self-regulations
CV 5	Public Investment	The amount of public resources in Turkey assigned to R&D in nanotechnology
CV 6	Profit potential	The business potential of nanotechnology, indicated by the worldwide private financial investments
CV7	Risk assessment	The available results provided by independent risk assessments on nanotechnology

Appendix 3a. The summary table for expected time of occurrences of nanotechnological applications using different methods and clusters.[7]

Focus variables	Cluster no:	N	Mean VALUES	STD. DEV.	Expected average time of occurrence
Increase of agricultural efficiency	1	21	2.19	1.289	2022
	2	10	2.2	1.033	2018
	3	18	2.67	1.495	2020
	4	20	2.25	1.02	2018
	5	30	2.63	1.402	2022
	Total	99	2.42	1.286	2020
Improvement of environmental quality	1	21	2.29	1.102	2020
	2	10	2.1	0.738	2019
	3	18	2.39	1.145	2020
	4	20	2.55	1.317	2020
	5	30	3	1.339	2023
	Total	99	2.56	1.222	2021
Increase of efficiency of energy systems	1	21	2.43	1.165	2021
	2	10	2.5	1.08	2019
	3	18	2.61	1.195	2020
	4	20	2.35	0.933	2019
	5	30	2.77	1.382	2022
	Total	99	2.56	1.18	2020
Enhancement of nutritional quality	1	21	2.33	1.317	2021
	2	10	2.4	1.174	2020
	3	18	2.83	1.689	2024
	4	20	2.8	1.473	2024
	5	30	2.9	1.561	2024
	Total	99	2.7	1.474	2023

[7] As mentioned in the text, different approaches for calculation have been used to determine the expected time of occurrences for nanotechnological applications. A kind of sensitivity analysis has been employed as to reduce any form of bias. Then, those results have been averaged and finally the averages of those calculations are taken as the main statistics. Interested readers may contact the authors for details.

Appendix 3b. The summary table for expected time of occurrences of nanotechnological applications using different methods and clusters.

Information technology hardware	1	21	2.1	1.179	2018
	2	10	1.9	0.738	2017
	3	18	2.39	1.145	2018
	4	20	2.15	0.933	2018
	5	30	2.47	1.358	2020
	Total	99	2.25	1.146	2018
Quality of medical and pharmaceutical products	1	21	2.33	1.238	2019
	2	10	2.1	1.101	2018
	3	18	2.44	1.149	2019
	4	20	2.45	1.099	2019
	5	30	2.73	1.23	2021
	Total	99	2.47	1.172	2020
Quality of cosmetic products	1	21	2.48	1.537	2020
	2	10	3	1.7	2024
	3	18	2	1.085	2020
	4	20	2.35	1.268	2019
	5	30	2.5	1.28	2022
	Total	99	2.42	1.348	2021
Decrease of production costs	1	21	2.57	1.363	2021
	2	10	2	0.943	2018
	3	18	2.44	1.247	2019
	4	20	2.45	1.234	2019
	5	30	2.47	1.196	2021
	Total	99	2.43	1.214	2020
Improvement of textile properties	1	21	2.52	1.47	2020
	2	10	2	1.054	2018
	3	18	2.28	1.179	2018
	4	20	2	0.973	2017
	5	30	2.3	1.291	2020
	Total	99	2.25	1.223	2019

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