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An Analytic Model for Quantitatively Assessing the Resilience Level of an Agri-Food Supply Chain: Development and Validation

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Abstract: Over the last decade, resilience has become an indispensable aspect to be considered when managing supply chains given to the recent challenges they were subjected to. However, despite literature on supply chain resilience is copious, tools for quantifying the resilience of a business are lacking, especially when dealing with the *a priori* resilience of a system, since several assessments are *a posteriori* carried out, after a disruption has manifested. In response, an analytic quantitative model is here proposed, whose output is a Global Resilience Index for a company. The model is divided into 3 phases: Supply (8 factors), Production (12 factors) and Distribution (5 factors); these elements were derived from literature and semi-structured interviews with practitioners. The logical functioning of the model is based on weighted averages attributed to each single factor; for defining the weights a survey was sent, in which respondents had to express their opinion with reference to the perceived impact of those factors on resilience. For validating the model, it was implemented in three companies manufacturing the following products: fresh milk, ginseng coffee and vegetable preserves. Despite none of them reached the higher resilience level, results offer interesting insights for let the users understand where the system is weaker. This model is intended to be made available to those who desire to include the resilience assessment to manage operational decisions.

Keywords: resilience assessment; resilience model; quantitative assessment; Global Resilience Index; food industry; food supply chain; agri-food; resilience factors; resilience indicators; quantitative model

1. Introduction

Research on supply chain resilience is incessantly ongoing; one and a half year ago, i.e., at the beginning of 2023, Scopus database counted more than 3 thousand paper focusing on "supply chain " AND "resilience" [1]. At the time of writing, in the second semester of year 2024, the same query returns two thousand documents more, thus demonstrating the attractiveness of the topic from the scientific community side. Among them, different definitions for supply chain resilience can be found, which can differ in key elements depending on the authors or context [2]; however, the most general definition refers to the resilience of a supply chain as the ability of the supply chain itself to withstand changes of steady-state and converge to the original state or to a new desirable one [3], implicitly including concepts of transformability, adaptability and robustness [4]. For other facets and variants, readers can refer to [2] who reviewed the existing definitions of supply chain resilience.

Reasons for this status change in the context of supply chains may be any form of disruption which could be due to natural disasters (e.g., tsunami, earthquakes, climate change, floods or droughts), to humanitarian health issues, such as the recent Covid-19 pandemic in 2020, or to political-economic problems such as those deriving from the current war in the Gaza Strip or from the conflict between Russia and Ukraine, still burning (and of course for other similar situations in the past). Raw material suppliers could be based in risky geographical areas for the reasons abovementioned; the same could happen for customers and market segments; consumers' habits could change, such as after a pandemic with lockdowns and restrictions; economic interests and rates could vary; shortages of components and spare parts could occur; lack of rain could get agriculture into trouble, as well as floods, the opposite issue. Resilience reflects the ability of not being perturbated from all these negative events which could happen. How to be resilient is the challenge. And this challenge has to be faced, since a recent study demonstrates that yearly more than 56% of companies globally suffer a supply chain disruption [5], and the hard globalization that characterizes our times more jeopardizes systems.

Recalling the attributes mentioned few lines above, i.e., transformability, adaptability and robustness, what differs among them is the timing these characteristics are manifested; indeed, the ability to transform is something that necessarily emerges after a disruption, because a transformation assumes a change starting from a pre- status to a post-one; in other words it can be seen as the responsive capacity of resilience, as other authors stressed [6]; adaptability, i.e., the coping resilience capacity, can emerge during a disruption, since a system, or in this case a supply chain, once it is in the middle of a disturbance or a change, has at the first impact to adapt itself; finally, the robustness of a system reflects the anticipatory capacity, namely the real resilience definition: the ability of being imperturbable, and accordingly to anticipate any negative impact that may occur. As far as the in and post status, several assessments were performed so as to respond to the following question: was the system resilient? On the contrary, a recent analysis revealed that assessing the AS-IS resilience level, so the robustness and anticipatory capacities of a system, represents an unexplored area of investigation [1], especially in the context of agri-food supply chains. Indeed, this field lacks of structured and reliable tools to manage and deal with resilience (e.g., [7,8]), and accordingly studies covering this gap were highly recommended from other authors.

The agri-food supply chain is one of the most affected field in term of resilience, above all by the climate change [9,10], but at the same time it is essential for our lives, since it provides the raw materials for our existence. Indeed, the agri-food supply chain includes agricultural holdings responsible for growing, harvesting activities and breeding farms but also transformation industries with processing activities and distributors [11,12][12], and faces unique vulnerability due to perishability, seasonality, weather effects, quality and safety requirements [13,14]. These elements make this specific supply chain more complex and sensitive compared to other supply chains.

As stated few lines above, this research originated from a practical need and from a lack in literature in terms of models and indicators for quantifying the resilience level of agri-food systems. In [1] a literature analysis was carried out, specifically in the agri-food context, so as to determine whether analytical models for quantifying resilience existed or not, and what emerged is a scarce contribution from the scientific literature in this sense. According to that, in this paper, the authors present the development of a model for quantifying the AS-IS resilience level of an agri-food system, with reference to a specific product.

After having carried out a thorough survey on Key Performance Indicators (KPIs) and factors affecting resilience, both through a literature review and with semi-structured interviews with stakeholders, a list of 25 indicators was derived, and a model was developed under Microsoft Excel ™. The output is a number, the Global Resilience Index, reflecting the resilience level of a specific company and as a consequence of its supply chain, and should suggest where the attention of the management should be focused in order to reduce the risks related to possible negative scenarios.

The remainder of the paper is structured as follows: section 2 proposes in detail the methodology followed for developing the model and defining the factors to be included; section 3 proposes the model, including preliminarily outcomes from the survey sent for defining the weights of each factor and the subsequent validation through three different case studies. Finally, section 4 concludes the manuscript with limitations and interesting insights for future research directions.

2. Methodology

The starting point for developing the model was the reference to a literature review whose details and outcomes are preliminarily proposed in [1]; moreover, for completeness, an additional search was carried out so as to be as complete as possible. Specifically, since in the previous work the focus was in the agri-food context, in this research the constraint of the field was removed; indeed, three different queries were performed on the Scopus database in September 2023, having the following keywords:

- "resilience" AND "supply chain" AND "quantitative model"
- "resilience" AND "supply chain" AND "metric*" AND "indicator*"
- "resilience" AND "supply chain" AND "metric*"

The first query returned a total of 17 documents, the second 7 while the most copious was the third, with 123. After having removed duplicates, papers not written in English language and not retrieved articles, the final sample was composed of 111 documents. Both bibliometric and contents analyses of these documents encompass the same steps followed in [1], and the most relevant outcome is the list of the 25 indicators to be included in the model, illustrated in the next section; indeed, the research question that accompanied this step of the research was the following: is there any indicator used for quantifying any aspect of the resilience in this reviewed document? For those interested readers, the details of this literature review can be provided; however, in this manuscript, for the sake of brevity it was decided to not deepen this part which is actually out of the scope.

Semi-structured interviews were in parallel carried out with practitioners of the food industry world; this part allowed to increase the list of factors included in the model, since respondents offered interesting elements not emerged from the literature search; results from this step are available in [15].

After having drafted the final list of the 25 factors, a survey was sent to a sample of 624 companies operating in the food context selected through Kompass database (https://it.kompass.com/a/prodotti-alimentari/03/d/parma/it_08_034/); into detail, after having selected the category "Companies - Food Products" available on Kompass, a filter was applied on the geography: indeed, only companies based in Parma (in the heart of the *food valley*, Northern Italy) were considered. Respondents, reached by mail, were asked to express their opinion with regard to the impact that these factors have on the resilience of their company (thinking to a specific product), on a ten-mode Likert rating scale (10-maximum impact, 1-minimum impact). The survey was anonymous; however respondents had to indicate the dimensions of their business, their role within the supply chain (i.e., supply, production or distribution company), the main final product they manage and their willingness to provide data and information for completing the assessment, for the subsequent validation of the model in question.

The survey was opened on Google Moduli for completion two months (March and April 2024), and after having collected the replies it was possible to derive the weight of each indicator, according to the analytical procedure illustrated together with the model itself in the following section.

3. Results

3.1. Model Structure and Resilience Factors Identification

As already anticipated, the literature review analysis represented the primary source for defining both the model structure and the factors to be included. As a first outcome, it can be stated that the theoretical/conceptual insights were significant and numerous among the reviewed documents, while the quantitative/analytical ones were substantially lacking in terms contents, as expected.

As will be duly specified below, the so-called "Resilience Factors" represent the basis of the model's hierarchical structure and their evaluation allows to determine what has been called the final "Global Resilience Index", defining the resilience level of the company which is performing the assessment, with reference to a specific product.

First of all, the idea behind the model is the decomposition of a company in its typical macro-phases, i.e., supply, production (or transformation) and distribution (or sales), each areas linked to the actors that constitute its supply chain; for each phase proper factors were identified, converging

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into a global synthetic index derived after having defined an appropriate mathematical calculation. However, note that for each phase a sub-score is also provided; accordingly, a potential user of the model can easily identify in which of the three abovementioned phases the system is weaker.

The procedural process of the model, therefore, follows two steps: the first one summarizing the Resilience Factors in the three sub-indices they refer to; the second one calculating the Global Resilience Index. Both these steps are carried out through an analytical procedure based on weighted averages (further details will be provided in the subsections that follow). The idea of hierarchically tracing the calculation of a complex index to the evaluation of several variables is not new in literature; for instance, this is also the approach adopted for defining the so-called Global Peace Index (GPI), developed to measure the level of peacefulness of a country (in this case, the calculation is traced back to the evaluation of 23 qualitative and quantitative indicators related to the level of security of a society, the extent of ongoing internal and foreign conflicts and the degree of militarization) [16].

Before moving on to a punctual description of the model functioning, the following tables list the Resilience Factors that were deduced from the initial literature analysis and interviews, with their relative sources. Response options, representing the input that practitioners or those interested actors who want to derive the resilience level of their business are required to enter, are included as well, and are listed in decreasing resilience order.

Specifically, Table 1 refers to the supply stage, Table 2 to the production and Table 3 to the distribution.

Table 1. Resilience factors for the supply stage.

Resilience factor	Source	Response options / completion	Factor description	Resilience interpretation
Suppliers number	[17]	- Multiple sourcing with backup supplier(s) - Multiple sourcing - Single sourcing with backup supplier(s) - Single sourcing	Number of suppliers for the main raw material of a product.	The greater number of suppliers and backup suppliers, the more resilient.
Frequency of deliveries	[17]	- Daily - Weekly - Monthly	Delivery frequence guaranteed from the main supplier.	The greater frequency, the more resilient.
Suppliers distance (geography)	[17]	- Regional - National - European Union (EU) - Extra EU	Geographical distance of the supplier who contributes with major raw material volumes.	The closer (i.e., regional level), the more resilient.
Geopolitical/war/terrorist problems of the supplier's country	[18]	The respondent is provided with a link for consulting the rate associated to the country of the main supplier (https://www.visionofhumanity.org/maps/#/), then the following options can be inserted: GPI < 1,599 GPI [1,600 – 1,988] GPI [1,900 – 2,199]	Risk/instability linked to the country of the supplier. The indicator used to define the ranges of this factor is the "Global Peace Index" [16] a tool developed to measure the state of peacefulness of	The lower value, the more peaceful a country is considered to be (hence less risky and more resilient).

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		GPI [2,200 – 2,499] GPI [2,500 – 2,799] GPI [2,800 – 3,099] GPI > 3,100	a country; it is yearly updated and already used among academics (e.g., [19] or [20])	
Contract(s) switching capability	[21]	- Flexible contract (or no contracts, so no constraint) - Monthly binding contract - Annual binding contract	Level of flexibility (in terms of duration and possible exit clauses) of the contract with the main supplier.	The more flexible and not binding, the more resilient.
Raw material seasonality	[22]	- Product always available - Product available in certain months of the year [5-8 months] - Product available in certain months-weeks of the year [4 or less months]	Availability of the major raw material over the year.	The more available, the more resilient.
Variability of raw material purchase prices	[23]	- Absent or almost absent [less than 10%] - Slight [up to 30%] - Strong [more than 30%]	Fluctuation in the purchase cost of the major raw material, compared to the previous year.	The lower the variability, the greater resilience.
Level of climate change impact on raw material	[24]	- Non-vulnerable product - Probable occurrence of problems - Sensitive product	Perceived vulnerability of the major raw material to climate change issues.	The less vulnerable product, the greater resilience.

Table 2. Resilience factors for the production stage.

Resilience factor	**Source**	**Response options / completion**	**Factor description**	**Resilience interpretation**
Production capacity	[18]	- Saturation ≤ 40% - 40% < Saturation ≤ 60% - 60% < Saturation ≤ 80% - Saturation > 80%	Production saturation level of the system. This factor is measured by the percentage of saturation of the productivity of the system.	The less saturation, the greater resilience
Labor availability and specialization	[18]	- Readily available labor - Hardly available labor	Ease of finding specialized labor to carry out production tasks (dependent on both the labor market and the level of flexibility of the operators	The easier, the greater resilience.

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			already employed).	
Number of production plants	[25]	- Multiple plant - Single plant	Level of decentralization of production capacity.	The greater number, the greater resilience.
Level of integration system and information sharing	[26]	- Information sharing - Each actor works independently	Information management among the various actors of the system especially, for instance, regarding the organization of promotional sales by the large-scale retail trade.	In case of information sharing and co-operation among stakeholders, a greater resilience level is expected.
Raw material stocks	[27]	- Monthly coverage - Weekly coverage - Daily coverage	Level of safety stocks for the major raw material. This factor is measured on the basis of the coverage production time guaranteed by the safety stock.	The greater coverage (i.e., monthly), the more resilient.
Energy self-sufficiency (electricity)	[28]	- Self-production ≥ 75% - 50% ≤ self-production < 75% - 25% ≤ self-production < 50% - Self-production < 25%	Self-production of electrical energy, therefore not dependent on external suppliers; the % is considered with reference to the total used electricity.	The greater self-produced energy, the more resilient.
Variability of consumables purchase prices	[23]	- Absent or almost absent [less than 10%] - Slight [up to 30%] - Strong [more than 30%]	Fluctuation in the purchase cost of secondary production components (e.g., ingredient such as thickeners, preservatives etc.), compared to the previous year.	The lower variability, the greater resilience.
Robustness to ICT problems	[29]	- Presence of a specific IT security program - Absence of a specific IT security program	Ability of the system to cope with cyber security issues.	The presence of an IT security program represents a plus

				in terms of resilience.
Perishability of raw material (and eventual preservation technology)	[22]	- Months of shelf-life - Weeks of shelf-life - Days of shelf-life	Shelf-life of the main raw material, before the transformation process. It depends on the intrinsic product characteristics and on the (eventual) preservation technology involved.	The greater last (i.e., monthly), the more resilient.
Flexible recipe	[15]	- Flexible recipes - Not flexible recipes	Level of flexibility of the transformation process (concerning the substitution of certain components, changing the percentages of particular ingredients, etc.)	A flexible recipe is associated to a higher level of resilience, as not strictly dependent on specific quantities and ingredients.
Frequency of meetings and production reviews	[15]	- Daily - Weekly - Monthly	Frequency of meetings to review the production program, related to the readiness of the system to cope with boundary changes (such as demand and/or supply conditions).	Meeting frequently allows to promptly address any problem; accordingly, for a greater resilience level daily meeting are recommended.
Cash availability	[15]	- High (X ≥ 20%) - Medium (10% ≤ X < 20%) - Low (X < 10%)	Cash availability determined as the percentage of cash out of the revenue of the last year.	A greater liquidity allows to respond to eventual problems, increases in prices or in investments; accordingly it was assigned the higher level of resilience.

Table 3. Resilience factors for the distribution stage.

Resilience factor	Source	Response options / completion	Factor description	Resilience interpretation

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Level of finished products stock visibility	[30]	- Presence of visibility (information sharing) - Absence of visibility (information sharing)	Information sharing among the different actors, so as to in order to mitigate the effects of order distortion (e.g., bullwhip effect) and delayed information.	In case of visibility and data sharing, the resilience increases.
Finished product stocks	[27]	- Monthly coverage - Weekly coverage - Daily coverage	Level of safety stocks of finished products. This factor is measured on the basis of the demand coverage guaranteed by the safety stock.	The greater coverage (i.e., monthly), the more resilient.
Sales mode	[31]	- Multi-channel - Online channel - Physical channel	The way in which the finished product reaches the end consumer.	Having multiple strategies for selling is clearly associated to a higher resilience level; however, among physical and online situations, a recent study shows that after having introduced the online channel, the physical one was cannibalized [32]; accordingly, to the online a higher resilience level was attributed.
Perishability of finished product (and eventual preservation technology)	[22]	- Months of shelf-life - Weeks of shelf-life - Days of shelf-life	Shelf-life of the finished product, before the distribution process. It depends on the intrinsic product characteristics and on the (eventual) preservation technology involved.	The greater last (i.e., months), the more resilient.

Instability of geographical export areas	[15]	As per the supply stage, the respondent is provided with a link for consulting the rate associated to the country where the majority of their products are sold. The response option are the same.	Risk/instability linked to the country of the purchaser. In this case as well, the indicator used to define the ranges of this factor is the "Global Peace Index".	The lower value, the more peaceful a country is considered to be (hence less risky and the more resilient).

As it is possible to deduce from the above tables, a total of 25 Resilience Factors was included in the model: 8 for the supply, 12 for the production and 5 for the distribution phases.

3.2. Survey Results

The survey was carried out in order to get insights into the perception of selected practitioners of the impact that the resilience factors have on the resilience level of their business, with the aim of determining the weight for each factor. Overall, 55 companies replied, corresponding to the 8.8% of the initial sample.

Most of the companies (25, namely the 45% of the whole sample) are small-sized or family conducted, followed by 17 medium companies (i.e., 31%); only 10 companies are small-medium enterprises (18%) and finally, only 3 companies declared to be of large size. These results reflects the Italian context: indeed, compared to the other European countries, Italy still has smaller farms [33] and the average number of workers within the food industry in 2021 was at 8 (12.2 for the beverage field) [34]. As far as the supply chain phase is concerned, as already highlighted, within the food industry three different phases can be found, and depending on the phase different actors can be involved; indeed, in the supply stage the production of raw materials is included, and generally farms are responsible for livestock and crops management; in the production stage, companies transforming these raw materials into finished products are involved, followed by the distribution channel, which can be represented by the last actors, i.e., supermarkets or shops or mere distribution operators, and the distribution strategies for reaching the final customer. Of course, these three macro-phases can also be found within a single company on a smaller scale, which is the bases for the present model. Within the sample, as expected most of the companies belong to the transformation phase (i.e., 43), while only 5 companies declared to specifically dedicate their business to distribution; only 4 are farms. The last tracked information for profiling respondents, was the final product they managed, and overall, what emerged is that the most common product among respondents (16 in total) is meat and cured meat, so a high value product. Other categories represented and worth of mentioning are pasta products (7); milk and dairy products (4); coffee (3).

These respondents were required to express their opinion with reference to the abovementioned 25 resilience factors, specifically thinking about the impact that these factors could have on the resilience of their business.

Results from this survey, in terms of mean and standard deviation, are proposed in the table that follows, Table 4.

Table 4. Survey results for the 25 Resilience Factors.

	SUPPLY	
Factor	**Mean**	**Standard deviation**
Suppliers number	6.80	1.99
Frequency of deliveries	6.20	2.13
Suppliers distance (geography)	6.18	2.44

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Geopolitical/war/terrorist problems of the suppliers' country	6.33	3.17
Contract(s) switching capability	6.33	2.23
Raw material seasonality	6.07	2.55
Variability of raw material purchase prices	7.40	2.03
Level of climate change impact on raw material	6.73	1.90
PRODUCTION		
Production capacity	6.87	1.88
Labor availability and specialization	7.07	2.10
Number of production plants	4.55	2.26
Level of integration system and information sharing	5.55	2.40
Raw material stocks	6.02	2.22
Energy self-sufficiency (electricity)	6.16	2.40
Variability of consumables purchase prices	5.22	2.48
Robustness to ICT problems	5.36	2.01
Perishability of raw material (and eventual preservation technology)	6.64	2.15
Flexible recipe	5.15	2.52
Frequency of meetings and production reviews	5.04	2.40
Cash availability	7.04	2.05
DISTRIBUTION		
Level of finished products stock visibility	5.93	1.88
Finished product stocks	6.05	2.09
Sales mode	6.27	2.27
Perishability of finished product (and eventual preservation technology)	6.69	2.03
Instability of geographical export areas	5.87	3.08

Overall, most of the factors range from 6 to 7 meaning they have a moderate perceived impact on resilience; standard deviations in these cases as well confirm that most of the respondents agree on the achieved scores. However, some exceptions are worth to be recalled: in primis, the most impactful perceived factor according to the sample in question is the "Variability of raw material purchase prices" (average score: 7.40), followed by "Labor availability and specialization" (7.07) and "Cash availability" (7.05). The latter is in line with the results from the semi-structured interviews, since almost all the companies agreed on its importance [15]. In contrast, the factor perceived as less relevant when dealing with resilience is the "Number of production plants" (4.55); in fact, this factor could strictly be related to the size of the company itself. Other interesting issues are related to the low scores achieved by ICT issues, namely "Level of integration system and information sharing" (5.55), "Robustness to ICT problems" (5.36) and "Level of finished products stock visibility" (5.93),

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given the fact that they achieved great importance in the previous interviews. Interestingly, instead, if the "Variability of raw material purchase prices" is the most relevant factor among the 25, the "Variability of consumables purchase prices" seems to not have the same importance; recently, several problems were recorded with spare parts such as electrical components, but evidently regarding the food areas and ingredients this is not a relevant issue. Moreover, again comparing similar situations, "Geopolitical/war/terrorist problems of the suppliers' country" is perceived as more important than for the export situation (6.33 versus 5.87); however, it should be noted that this factor is the one which returned the greater standard deviation level (3.17); in fact, the perceived opinion strictly depends on the situations of respondents (i.e., where their suppliers are located). Finally, contrary to the findings when interviewing companies, less attention was paid towards the possibility of having flexible recipes and to the frequency of internal meetings for monitoring different scenarios and markets.

Outcomes from this survey were preliminary to define the model functioning; indeed, the selected calculation procedure is based on weighted averages, able of synthesizing information by attributing different importance to different resilience factors. This procedure is detailed in the subsection that follows.

Note that all the factors were included in the model, regardless their results of Table 4; indeed, their contribution to the Global Resilience Index will be proportional to the attributed importance, but their relevance was deduced from scientific sources.

3.3. Model Functioning and Factors' Weights Determination

Once having collected the opinions of the experts, the weights assigned to each factor can be determined. Firs of all, it should be noted that the factors are not all associated with the same rating scale, which depends on the number of response options. Indeed, for instance, the resilience factor "Supplier distance (geography)" is rated by four modes with associated values ranging from 1 to 4, while again for example "Raw material seasonality" by three modes, with values ranging from 1 to 3. According to these two examples, it can be easily deduced that the modes are defined by the number of response options (with reference to that see the previous Tables 1, 2 and 3).

In order to proceed, then, each factor was related to a common scale so as to make the assessment objective and mathematically correct.

For the sake of clarity, the procedural calculation steps are listed below:

- *Adoption of a common scale for determining the scores for each response option*: this step addresses the concepts expressed few lines above, by means of simple proportions. Recalling the abovementioned "Supplier distance (geography)" factor taken as an example, this factors has 4 response options, and accordingly 4 modes; an input rate of 3, for instance, corresponding to the response "Multiple sourcing" would correspond to a score of 75, assuming a 100-based scale. The value of 75 is derived by applying the proportion 3/4 * 100, where 3 corresponds to the response option selected by the user (listed in decreasing order of resilience), and 4 to the total of response options. By extending this reasoning to each factor, the formula involved for determining the points associated with each response option is the following:

$$Rate_{Response\ option} = \frac{mode\ associated\ to\ the\ response\ input}{number\ of\ response\ options} * 100 \quad [1]$$

It is recalled that the modes associated with the response input are listed in decreasing order of resilience. Table 5 below details these step for the factor taken as an example.

Table 5. Example of calculation of the scores for the first Resilience Factor.

Factor	**Response option** (in brackets the modes associated to each response option; higher values mean higher resilience level)
Supplier distance (geography)	- Regional (4) - National (3) - EU (2)

	- Extra EU (1)
Rate of each response (by applying eq. [1])	$Rate_{Regional} = \frac{4}{4} * 100 = 100$ $Rate_{National} = \frac{3}{4} * 100 = 75$ $Rate_{European\ Union} = \frac{2}{4} * 100 = 50$ $Rate_{Extra\ European\ Union} = \frac{1}{4} * 100 = 25$

Note that 100, 75, 50 and 25 correspond to the rate associated to the specific response option.

By repeating the same procedure for each factor, one can determine the score for each response option; clearly, higher values are related to a higher level of resilience.

- *Absolute weights calculation*: in this step, the absolute weight of each factor is calculated by summing each impact value expressed by the survey respondents (i.e., 55 values, ranged from 1 to 10, for all the 25 Resilience Factors).
- *Relative weights calculation*: in this step, the previous absolute weight of each factor is divided for the sum of all the total weights of the single factors; note that this operation is carried out independently for each supply chain phase: this means that each of the three phases will have its own sum of absolute weights for its factor list.
- *Resilience Factors values determination*: each score achieved by each factor is computed by multiplying its relative weight for the rate of each response achieved in the first step (clearly depending on the provided input response). The relative weight is fixed, while the other factor varies according to the response provided by the potential user.
- *Resilience index for each phase determination:* the score achieved by each of the three phases is simply achieved by summing all the single resilience factors values obtained in the previous step.
- *Global Resilience Index determination:* at this point, the apex of the model's hierarchical structure is calculated using the following sub-steps*:*
    a. *Absolute weights for each phase determination*: the absolute weight of each phase is determined by averaging the impacts of the individual factors provided by the respondents (again, distinguishing phase by phase); for example, for the Supply stage, being 55 respondents and 8 factors the average value is determined by dividing the sum of the values for 440 (55*8=440);
    b. *Relative weights for each phase determination*: in this sub-step, the relative weights of each phase are calculated by dividing the corresponding absolute weights achieved in the previous step by the sum of the three absolute weights sum;
    c. *Final index for each phase calculation*: this value is achieved by multiplying the relative weight for each phase determined in the previous step for the Resilience Index of each phase;
    d. Global Resilience Index achievement: sum of the three components of each phase.
- *Resilience assessment:* in this last step, the achieved numerical values (i.e., Global Resilience Index and the 3 indices for each phase) are associated with a qualitative evaluation of the "High-Medium-Low" resilience level; this interpretation is detailed in the next paragraph.

From the side of a hypothetical user, he/she will simply have to select for each factor the relative selected response option, and in a fully automatic manner the model will output the value of the resilience of the system (with its sub-indices) and the corresponding rating.

Before going any further with detailing the qualitative interpretation of the resilience level, it is necessary to point out an important concept: according to how the Resilience Factors and their modalities have been defined, the numerical lower limit of the index rating scale is non-zero. It is easy to understand that this is not a constraint on the application of the model; a value is not important, but becomes meaningful when related to a rating range, regardless of the value of the extremes. This reasoning will also be stressed and further discussed in the remainder of the document.

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As far as the practical structure of the model is concerned, the Microsoft Excel™ file is divided into 6 spreadsheets, whose contents are hereafter defined:

- "User interface": this represents the first spreadsheet, and the one the respondent has to deal with. Indeed, he/she will enter the input information, which are listed in a cell by means of drop-down menu. The other two tables referred to the Production and Distribution phases are positioned below in the same sheet, and a final Table proposes the achieved numerical result, determined in an automatic manner according to the response options selected by the user (a conditional formatting rule is applied so as to draw the attention and let immediately understanding the level).
- The three following spreadsheets renamed "Supply", "Production" and "Distribution" are similar, and shows the tables for the evaluation of the Resilience Factors (modalities and numerical values). All the tables related to the single factors are included, of course.
- In the penultimate sheet, as its name suggests, namely "Weights", the results from the survey can be found; note that this sheet is preliminary to the calculations of the last spreadsheet.
- The last spreadsheet, named "Calculations", hosts all the practical steps detailed when illustrating the model functioning. This sheet is linked to the User Interface, allowing to derive the final score of each phase and the Global Resilience Index. Five columns are reported after the column related to the factor: "Value" column associates the ways in which the factors have been declined with the respective numerical evaluations (in other words this column is related to the User Interface and the input responses, actually randomly assigned in this screenshot); the "Scale value" column relates them to a common scale (in this case with an upper limit of one hundred); the "Absolute weight" and "Relative weight" columns determine the weights of each factor, while the column marked with suspension points calculates the addends of the sums necessary to define the three sub-indices (shown in the bottom right-hand corner of the sheet). A final table summarizes the three calculated values in the overall resilience level. One last remark on the conditional formatting applied on this table: the numerical values of the indices were associated with qualitative evaluations according to a subdivision of the intervals into three bands, corresponding to a 50-30-20 percentage distribution. The resulting values and threshold are proposed in the table below (Table 6).

Table 6. Scores interpretation.

	Low Value	Medium Value	High Value	Maximum Value
Sub-index of Supply	28.94	64.47	85.79	100.00
Sub-index of Production	38.32	69.16	87.66	100.00
Sub-index of Distribution	32.91	66.45	86.58	100.00
Global Resilience Index (GRI)	33.24	66.62	86.65	100.00

According to the above table, with reference to the overall global index, if a score falls below the medium value, i.e., 66.62, the qualitative grade associated is low; conversely, in case of the range [66.62 - 86.65] the relative score is medium, high in the remaining cases (corresponding to the so called "Green Zone"). Same reasoning goes for the sub-indices, but with different thresholds according to the related calculations. For a better understanding, 33.24 corresponds to the case in which the user selects all the worst responses, with a lower resilience level; 100 instead means that the user chose the best options. The medium threshold of 66.62 is achieved by the following formula: 33.24 + 0.5 * (100 - 33.24); the higher, instead: 33.24 + 0.8 * (100 - 33.24). The 0.5 and 0.8 (= 0.5 + 0.3) derive from the selected above mentioned rule, 50-30-20. The same calculations are repeated for the sub-indices.

Overall, it can be stated that from the point of view of an hypothetical user the use of the model is simple and intuitive, as the only step required is to enter the information in the combined boxes

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associated with the various resilience factors; all the indices are automatically calculated and displayed immediately after the data entry tables.

3.4. Model Validation: Case Studies

For validating the model, three case studies were carried out, corresponding to those company who declared their availability in sharing data for this step in the survey. Specifically, Company A is a large producer of milk and dairy products; Company B is medium-sized and produces coffee and beverages in capsules; finally, the small-sized Company C produces vegetables preserve. Accordingly, they manage different products which can be sensitive to different potential problems, and they represent different dimensions but are all transformation firms. Note that the raw materials for their products all derive from farms (livestock in one case, crop cultivation in the other two).

Starting from Company A, with reference to the factors' impact, they believe that the most relevant is the "Sales mode" (10), meaning that multichannel is essential for being resilient; on the contrary, the two elements less considered (both judged 6) are the "Labor availability and specialization" and "Raw material stock". The former is in contrast with the outcomes from the survey; however, it should be noted that large companies are scarcely represented among the respondents sample. For the medium-sized Company B, instead, there are several factors deserving attention (perceived impact: 10), namely "Geopolitical/war/terrorist problems of the supplier country" (suggesting that they import raw materials), "Contract(s) switching capability", "Variability of raw material purchase prices", "Labor availability and specialization", "Flexible recipes" (in contrast to the trends of the survey's outcomes) and "Cash availability"; among the less relevant, instead, their opinion recall that of the majority of respondents. The last small company, instead, perceives as the most relevant factor the one related to the electricity self-production, while not relevant at all "Geopolitical/war/terrorist problems of the supplier country", the "Number of productive plants" and information sharing with other stakeholders. Results from their assessments are proposed in Figure 1. Specifically, the products to which results are referred are Fresh Milk (in bottles) for Company A; Ginseng coffee (in capsules) for Company B and Vegetable Preserve for Company C (they did not specify the specific vegetable).

Fresh Milk	
Phase	**Index**
Supply	93,52
Production	80,73
Distribution	56,14
GRI	77,05

(**a**)

Ginseng Coffee	
Phase	**Index**
Supply	75,03
Production	56,33
Distribution	83,71
GRI	71,98

(**b**)

Vegetable Preserve	
Phase	**Index**
Supply	74,78
Production	44,40
Distribution	87,66
GRI	69,42

(**c**)

Figure 1. Assessments of the case studies used for validating the model. (**a**) Company A results; (**b**) Company B results; (**c**) Company C results.

As it can be deduced from Figure 1, none of the companies got at least 86.65 as score (see the previous Table 6 for interpretating outcomes), which represents the threshold value for being defined as fully resilient. However, the large Company A is the closest, as expected. The conditional formatting immediately allows to understand where the attention should be addressed; indeed, red means a sort of alert, corresponding to the areas in which a company is weaker. Focusing again on Company A, the Supply stage got an excellent score; indeed, in almost all the factors they selected the most resilient option, exception made for the issue related to the situation of the supplier's country. In this case (but also for the other two companies) the country in question is Italy, and according to the 2023 results from the GPI, Italy is ranked in the second class [16]. As far as the raw material purchase cost variation, the company correctly selected absent variation, as supported by an updated report [35], which states that in the last year the percentage variance of the price for 100 kilograms of milk at the barn in Italy was negative. Production as well got a quite satisfactory result, clearly influenced by the fact that dealing with a fresh product, the raw material has a daily coverage and the product has a stringent shelf life. The remaining factors has what it can be expected from the side of a large and structured company: higher level of self-produced electricity, multiple plants, information sharing and IT security programs. Also, Company A does not have any problem in finding manpower; indeed, it was the factor that they perceived as not impactful for the resilience level of their business. For concluding the comment on the assessment of Company A, the lower score corresponds to the Distribution; indeed, despite, the data sharing, the product is fresh, and only through a physical channel in Italy, elements contributing to a rate in the yellow zone.

Company B is weak in all the areas, especially in terms of production. Regarding Supply, despite they have multiple suppliers they do not have any backup, which could constitute problems in case of disruptions; moreover, they manage a raw material which is always available during the year, but could be subjected to the effects of climate change, thus jeopardizing production. They declared to have problems in finding manpower, and do not have any source of energy other than the public service (same for Company C, inter alia). These are surely elements which distinguish small-medium sized companies from large companies, together with the frequency of meetings for discussing the market trends (monthly for Company B) and the lack of information sharing with the other actors of the supply chain. So, despite they manage a product with flexible recipes and months of shelf-life, their organization has a resilience level which should be revised. The same observations apply for Company C, the smaller; in fact, for Supply and Production the scores are similar to those of Company B. However, they demonstrated to be strong in the Distribution phase, even more than the large company; indeed, they have both physical and online channels for their sales, and given the intrinsic features of their finished product it can last for years, without stringent shelf-life. Moreover, they have stocks enough for covering months of potential demand from the side of customers; the probable reason is that they do not share the data related to inventory of their customers, and accordingly they should be ready and prepared to cover any request. With reference to the IT systems and data sharing and visibility, instead, Company C is quite deficient.

Finally, note that these respondents did not enter the response options into the model, but they filled in a paper form; accordingly, with reference to the user side, no insights can be derived on the ease of usage and comprehension of the Excel model itself. What can be here stated, is that according to the experience and to the opinion of the authors the model and the scores are properly set, and that the ranges are fair.

4. Conclusions

This research became necessary therefore the authors and other researchers noted that in the literature there were no structured models for assessing the AS-IS resilience level of a company (with reference to a certain product); moreover, other authors stressed the need to close this gap, since most of the research deals with assessment post disruption, namely when a disruption has already occurred and potentially had negative impact on the business. Instead, by a priori knowing the situation and where the system is weaker should help practitioners in undertaking operational decisions so as to be robust.

Accordingly, to close this gap, the authors here propose a model for quantitatively assessing the resilience level of a company operating in the food context.

Starting from a literature analysis and some semi-structured interviews, a set of 25 factors impacting on the resilience of a system was derived; these factors were properly classified according to the phase they refer to, which can be the Supply stage, the Production and the Distribution. The impact that these factors have, translated into the weight that they should had in the model, was defined according to the results from a survey carried out among companies based in Parma (North of Italy), in which the companies involved had to rate from 1 (no impact) to 10 (strong impact) each factor, when thinking to their business and their products. According to these outcomes, a model based on weighted averages was defined under Microsoft Excel™, in which against certain responses provided by a potential user, the outcome is a Global Resilience Index quantifying the resilience level of the company under examination; also the single scores for each of the three phase are available, suggesting where the focus should be addressed thanks to a conditional formatting. The model was then implemented on three case studies; despite none of them reached a fully resilience level, this validation could demonstrate the applicability of the tool.

Despite the positive achieved results and the developed tool, surely the present study has some limitations; first of all, the achieved responses from the survey were only 55, a reduced number compared to the initial sample. Moreover, replies strictly depend on the experience and the characteristics of the single company/product; for instance, if a company deals with a fresh product, will necessarily have a lower score than one producing long-life food. Again, a company not exporting their products surely would pay less attention to the factors regaling the situation of the countries of customers. And also results would reflect these issues. For addressing this issue, surely in the future it is expected to increase the number of respondents, so as to make the model statistically stronger. However, despite some companies could have limitations due to their intrinsic nature, this tool could represent a stimulus: they can see the other response options and understand which is the best situation, and accordingly strive to achieve it. They could be inspired in thinking to a technological solution for increasing shelf life of raw material and products, they could think of exploring new channels for their sales, or R&D areas could think on how to allow the recipes to be flexible and adaptable. In other words this could represent food for thought to ask how to reach a higher resilience level.

Moreover, the User Interface will be improved so as to make it as user friendly as possible, and some companies will be involved for a testing session, whose expected outcome is a feedback on the acceptance and usability of the tool; an online version is also under development, so as to make this tool available for more companies. The model could be easily adapted to other contexts as well, by selecting common factors and carrying out a similar literature investigation on KPIs used in that specific field, and emulating the weights determination by means of a survey.

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