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Title: Analyzing Intersectoral Water Relationships by means of Graph Theory

Author: Esther VELÁZQUEZ ALONSO

University: Pablo de Olavide (Sevilla, España)

E-mail address: evelalo@dee.upo.es

Abstract

The objective of this paper is to analyze the relationships between the productive sectors of an economy and the water consumption required by these sectors to generate their production. The research focuses on Andalusia, a region in the South of Spain which is characterized by water shortage. We address the question of whether the excessive dependence on water resources evidenced by some of the production sectors of the region might negatively affect not only the conservation and quality of this natural resource, but also the economy's soundness. The analysis makes use of a mixed methodology which combines Input-Output modelling with Graph Theory. The former framework allows us to define a model of water consumption, from which a matrix of intersectoral water relationships is created. Graph Theory is then used to analyze the relationships included in the matrix.

It is concluded that the Andalusian economic specialization not only does not foster conservation of water, but it could also endanger the regional economy if policy planners do not take into account water shortage when designing the region's economic policy.

1. Introduction

The objective of this paper is to analyze the relationships between the productive sectors of an economy and the water consumption required by these sectors to generate their production. We attempt to advance the arguments necessary to define a more rigorous and realistic economic policy that takes into account not only conventional economic aspects, but also environmental considerations.

The research presented here focuses on Andalusia, a region in the South of Spain which is characterized by water shortage. We address the question of whether the excessive dependence on water resources evidenced by some of the production sectors of the region might negatively affect not only the conservation and quality of this natural resource, but also the economy's soundness. An attempt is made to answer this question by determining which Andalusian economic sectors consume the highest quantities of water, and therefore exhibit the highest dependence on this resource. Additionally, we will consider to what extent this potentially excessive dependence could limit the regional economic growth[1].

Our analysis makes use of a mixed methodology which combines Input-Output analysis with Graph Theory. The starting point is the Matrix of Intersectoral Water Relationships, to which we apply the tools provided by Graph Theory. This methodology allows us to analyze in detail the water consumed by each productive sector, as well as the transactions of water which take place within the economic system. The resulting graphs enable us to visualize the water circuit in the Andalusian economy.

The Input-Output Model, defined by Leontief in 1936 for the analysis of intersectoral relationships in the American economy, was extended in the late 60's (Isard, 1968) with the purpose of analyzing the relations between an economy's sectoral structure and its environmental effects. The extended Leontief model has been profusely used to analyze energy and, more specifically, emissions of pollutants into the atmosphere[2]. However, very little attempt has been made so far to use the model for the analysis of the relationships between the production structure and water resources, and even less to combine the extended Leontief model with Graph Theory. This can be attributed to the fact that Graph Theory has been applied mainly within the framework of business and managerial studies, and it has been seldom used to analyze environmental effects. A notable exception is the work of Morillas (1996), in which Graph Theory is applied to the Input-Output Model in order to study the 'sensitivity' of the water producing sector to variations in the demand for other goods.

The research presented here attempts to take a step forward in the study of the relationships between Economy and the management of water resources. In the work of Morillas cited above, water is analyzed as a 'productive sector'; in contrast, we consider water to be a 'productive factor', a factor which is a scarce natural resource that is used by all sectors in their respective production processes with little regard for its scarcity. We will proceed further to determine the effects that the consumption of the 'water

[1] The analysis is based on data extracted from the Andalusian Input-Output Table, 1990 (*Tabla Input-Output de Andalucía*, TIOA-90), issued by the Andalusian Institute of Statistics, and the Andalusian Environmental Table, 1990 (*Tabla Medioambiental de Andalucía*, TIOMA-90), issued by the Andalusian Environmental Agency.

[2] Hawdon and Pearson (1995) provide an in-depth analysis of different works on this topic.

factor' may have on the conservation of this resource, as well as possible consequences on the economy.

In order to achieve this objective, we attempt to adapt a non-conventional methodology, namely, Graph Theory, to the standard econometric methodology – Input-Output modelling. This mixed methodology will allow us to deal with some aspects which are absent from input-output models, aspects which are fairly important in a structural approach, such as the relative positions of the different sectors in the production network and the influence of the water circuit on the economic structure. Additionally, this methodological combination enables us to visualize intersectoral relationships, both direct and indirect, related to water consumption in Andalusia. In short, it allows us to synthesize quantitative calculations and the 'topologic' knowledge of the production structure (Morillas, 1983, 120).

It is well known that water is not a homogeneous resource, and that a distinction can be made between drinking water (intended for human consumption) and not drinking water. This distinction must be stressed because it poses certain relevant questions, such as the need to analyze the quality of water according to the uses it is intended for. The allocation of water to different uses can thus be seen as a crucial issue, since not only water shortage, but also pollution of water resources has to be taken into account. Unfortunately, current statistics do not allow us to address this question in the present paper, thus our research is constrained to the only data available, namely, those issued by the Andalusian Environmental Agency. It is therefore impossible to determine whether or not a distinction between the uses and qualities of water is currently being made.

This paper is organized in four sections. After this introductory section, we will present the Matrix of Intersectoral Water Relationships, along with the methodology used for its construction. We will also explain how the elements of the matrix can be interpreted.

In the third section, the tools provided by Graph Theory will be applied to the above-mentioned matrix in order to analyze intersectoral water relationships. Finally, some conclusions will be drawn from the preceding analysis, and we will discuss how to design an economic policy adapted to reality, that is, one that approaches water consumption from the perspective of a region – Andalusia – characterized by water shortage.

2. The Matrix of Intersectoral Water Relationships

In this section, we will define a matrix showing all transactions among the different production sectors of the economy, with elements expressed in terms of water. Thus we obtain an n matrix (where n is the number of productive sectors) which includes all intersectoral transactions in terms of water. We shall call this the Matrix of Intersectoral Water Relationships.

To obtain the expression that defines this matrix, we start from an Input-Output model of water consumption, whose variables can be formulated as follows:

W: n matrix of intersectoral relationships in terms of water.

w_t: nx1 vector of total water consumption.

w_d: nx1 vector of direct water consumption.

w^y_d: nx1 vector of direct consumption to satisfy the sector's own demand.

w^*_d: nx1 indicator of direct water consumption per unit produced.

Q: n matrix of technical coefficients of water.

q_{ij}: technical coefficient of water; element of Q defined as the quantity of water consumed directly by sector j in generating products for another sector i, relative to the total quantity of water consumed directly by j.

$(I - Q)^{-1}$: Leontief inverse n matrix in terms of water.

L: n matrix of water distribution coefficients.

l_{ij}: water distribution coefficient; element of L defined as the quantity of water consumed directly by sector j in generating products for another sector i, relative to the total quantity of water consumed directly by i.

The Input-Output model of water consumption is defined by equation (1) below, where **u** is an nx1 unit vector, (‘) indicates transposition, and (^) diagonalization. This expression shows the total amount of water consumed by the production system in order to satisfy its own demand. In other words, the equation indicates how much water is required by the economic system so as to meet the demands of every single productive sector.

(1) $$w_t' = u'(I - Q)^{-1}\hat{w}_d^y$$

w^y_d above was earlier defined as the quantity of water consumed directly in order to meet a sector's own demand. Thus, by definition, we can obtain this vector analytically as follows:

(2) $$w_d^y = \hat{w}_d^* y$$

where w^*_d is the nx1 indicator of direct water consumption per unit produced, defined as direct consumption per production unit (Proops[3], 1998). In other words, this indicator shows how much water a given sector must consume in order to produce one value unit of goods.

By substituting this expression in equation (1) above and diagonalizing vector ***y***, the matrix is finally obtained (Table 1):

(3) $$W = (I - Q)^{-1}\hat{w}_d^*\hat{y}$$

Table 1 shows a square matrix which lists all 25 productive sectors both in rows and in columns. This matrix represents the intersectoral water relationships that are established between the sectors, expressed in thousands of cubic metres. Hence we can interpret and analyze the 'sales' of water a sector makes to another sector, and the 'purchases' of water a sector makes from another sector. By 'purchase of water', we understand the following: if a sector i buys a given product from sector j, then the quantity of water i buys from j is the quantity of water that sector j has consumed in generating its product (the reverse argument holds true for 'sales of water'). At this point, it is important to distinguish between the two possible types of consumption, that is, direct and indirect consumption. A sector consumes water directly when it takes it directly from the water supply mains; on the other hand, indirect consumption must be understood as 'purchase' of water as defined above. Consequently, in the aforementioned example, sector j consumes water directly, whereas sector i consumes water indirectly.

Two other matrices can be obtained from our matrix: the matrix of technical coefficients of water (Table 2) and the matrix of water distribution coefficients (Table 3). The former, if read by columns, indicates the amount of water every sector i buys from sector j. The matrix of distribution coefficients, if read by rows, expresses the quantity of water sold by sector i to the rest of sectors.

3. Analysis of water transactions

Either of the two matrices just defined could be used to analyze the amount of water consumed by the different productive sectors in Andalusia by means of Graph Theory. However, our analysis is based solely on the matrix of distribution coefficients and not on the matrix of technical coefficients, since we believe the study will be more objective if it is based on the *relative influence graph* instead of the absolute influence graph, provided that the relative influence between two sectors is the relationship between the

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[3] Proops's analysis focuses on energy consumption.

relative variation in a sector's production and the relative variation in another sector's demand. Our decision to use the matrix of distribution finds support in Morillas (1983, 160). The relative influence graph weights the intensity of two sectors' relationship according to the relationship between their productions, whereas the absolute influence graph takes into account *only* the relation between two sectors, without weighting it.

We will analyze water transactions from three different perspectives. Firstly, we will determine direct relationships by means of the analysis of direct causality. Secondly, we will analyze indirect causality in order to show indirect water relationships. Finally, we will define a sectoral hierarchy to account for the dependence on water of the different sectors.

The enormous amount of relationships that exist between sectors practically rules out the possibility of analyzing each of them in detail. For this reason, we have chosen to classify distribution coefficients according to the intensity of the relations they represent. Thus we define four situations for each case:

a) Very weak relationships: coefficients below or equal to 1%

b) Weak relationships: coefficients between 1% and 5% (inclusive)

c) Medium relationships: coefficients between 5% and 10% (inclusive)

d) Strong relationships: coefficients above 10%

3.1. Analysis of direct causality

The analysis of direct causality determines whether a *direct* relationship exists between two sectors i and j, and also whether that relationship is symmetrical or not, that is, whether i buys water directly from j or sells water directly to j. These direct relationships are represented in the incidence matrix (P), whose elements p_{ij} can be defined as follows:

- If a sector i sells directly to another sector j, then the element p_{ij} of the incidence matrix equals 1.
- If such a direct relationship does not exist, then $p_{ij} = 0$.

The incidence matrix allows us to determine integration of sectors according to water 'sales' and 'purchases', as well as the dependence or direct influence each sector exerts on the rest of the sectors of the economy. These relationships can be determined by calculating the semidegrees of the sectors in a graph. The exterior semidegree[4] of sector i ($\mathbf{s}_i\ \mathbf{(+)}$) expresses the number of sectors to which i sells directly, thus representing

[4] *Exterior semidegree* or *outdegree* is defined in Graph Theory as the number of directed edges outgoing from vertex i.

integration according to sales[5], and results from the row sums of the elements of the incidence matrix for each sector.

(4) $$s_i(+) = \sum_{j=1}^{n} p_{ij}$$

On the other hand, the interior semidegree[6] of sector i (**s_i (-)**) indicates the number of sectors from which i buys directly, thus representing integration according to purchases, and results from the column sums of the incidence matrix for each sector.

(5) $$s_i(-) = \sum_{i=1}^{n} p_{ij}$$

Having thus defined semidegrees, they can be interpreted as follows. The larger the exterior semidegree of sector i is, the greater the number of sectors which 'sell water' to that sector i is. Conversely, the larger the interior semidegree is, the greater the number of sectors from which sector i 'buys' water-intensive products is[7]. Therefore we are interested in determining which sectors exhibit the largest semidegrees – particularly, interior semidegrees – so that we can determine which sectors are the most dependent on water.

Semidegrees can be used to obtain the Net Dependency Index (NDI), which is defined as the quotient between the interior and exterior semidegrees and which indicates the sector's *dependence*, as well as the *direct influence* it exerts on the economy. The higher this index is, the greater the sector's purchases are and, accordingly, the greater dependence it exhibits.

Based on the classification of sectors according to their relationships' intensity described above, we have created four incidence matrices (P, P1, P5, P10) and their respective associated graphs (G, G1, G5, G10), each representing a different level of intensity in the relationship:

a) P and G: incidence matrix and graph showing all relationships in terms of water.

[5] Some researchers (see Morillas, 1983) consider that the exterior semidegree indicates integration of sectors according to purchases, whereas the interior semidegree indicates integration of sectors according to sales. This interpretation arises from the fact that these authors use the transposed matrix of technical coefficients. However, we have chosen not to transpose the matrix, what has not altered the results obtained. Thus, the exterior semidegree indicates integration by sales, and the interior semidegree indicates integration by purchases.

[6] *Interior semidegree* or *indegree* is defined in Graph Theory as the number of directed edges incoming to vertex i.

[7] It must be taken into account that we are considering here only the *number of sectors* involved in a given relationship, not the *quantity of water* that is bought or sold.

b) P1 and G1: incidence matrix and graph representing all relationships, except the weakest ones, that is, all coefficients above 1% are included.

c) P5 and G5: incidence matrix and graph representing medium and strong relationships. Therefore, coefficients above 5% are included.

d) P10 and G10: incidence matrix and graph showing only strong relationships, i.e. with coefficients above 10%.

Table 4 shows the semidegrees and NDIs of the four graphs listed above. The first noticeable result is that, if graph G10 is compared with the initial graph G, 93% of the relationships disappear, with G10 showing only the 33 strongest relationships. This means that despite the fact that a high number of water-based relationships might be thought to exist (since graph G shows 537 relations), the analysis proves that most of these relationships are practically insignificant, since graph G10 includes only 33, that is, only 6% of all water-based relationships are actually relevant according to their intensities. It can be thus observed that water relationships are basically restricted to certain sectors of the Andalusian economy, particularly, to the agricultural sectors, which are those that exhibit the strongest sales relationships.

The conclusions that can be drawn from the analysis of purchases are even more interesting. The sectors which exhibit the strongest relationships according to purchases are Food and Agriculture Industry (14), Construction (20), Textiles and Apparel (15), and, to a lesser extent, Hotel and Catering Trade (22). In other words, these are the sectors that buy water from the greatest number of sectors, thus establishing a very strong relationship. Therefore, these sectors' demand has a decisive influence on the water consumption of every other sector that supplies them with the products they require. Sectors 14, 20 and 15 are the most dependent on water, since they exhibit the highest NDIs.

3.2. Analysis of indirect causality

The incidence matrix and its associated semidegrees reflect only direct relationships between sectors. It is of interest, however, to extend the analysis so as to account for *indirect* relationships, thus describing the sectoral hierarchy with relation to water consumption in the Andalusian production structure. This analysis can be carried out by means of the *path matrix* (K) and the *distance matrix* (F).

The path matrix (K) indicates whether at least one path exists between i and j, that is, whether sector j can be reached from sector i[8]. Thus we obtain a square n matrix, composed of zeros and ones, whose elements are defined as follows:

- $k_{ij} = 0$ if j is not reachable from i.
- $k_{ij} = 1$ if j is reachable from i, either directly or indirectly.
- The main diagonal is 1 because each sector is related to itself.

The distance matrix (F), obtained from the path matrix, is a square n matrix whose elements f_{ij} represent the minimum distance between two sectors i and j with relation to sales.

- By definition, $f_{ij} = 0$, that is, the distance between a vertex and itself is 0. Therefore, the main diagonal of the matrix is 0.
- If there is no relationship between two vertices, either direct or indirect (hence $k_{ij} = 0$), the distance between them is regarded as infinite, $f_{ij} = \infty$.

If the weakest relationships are removed from the analysis, the path matrix K1 shows that some sectors are unrelated with regard to sales, that is, they do not sell water to any sector, except to sector 2 (Vegetables and Fruits). Thus, the interdependence which could be observed in matrix K and in its associated graph now disappears. It can then be argued that that interdependence was actually based on very weak, irrelevant relationships, as stated earlier.

The most noticeable conclusions that can be drawn from the preceding analysis are, first, that the Andalusian economic sectors whose demands exert the most decisive influence on water consumption are Food and Agriculture Industry (14), Construction (20), and Hotel and Catering Trade (22). This result is particularly relevant since it points to the fact that although these sectors do not consume great quantities of water directly, the products which are part of their productive processes do need great quantities of water. Then, the sectors consume water indirectly and are highly dependent on this natural resource. However, it is even more relevant that these three sectors are considered to be the 'driving forces' of the Andalusian economy, which means that the most important sectors in production and employment are also those which consume the greatest amounts of water.

[8] In other words, the path matrix shows whether a finite sequence of sectors exists, in such a way that there is always a directed edge from one sector to the next.

3.3. Hierarchical analysis

In this section, an attempt will be made towards establishing a hierarchy of sectors according to the influence they exert on the water consumption of the economy. For this hierarchy to exist, there must be a strict causality relationship between the sectors, that is, a non-reciprocal relationship, bearing in mind that a *reciprocal* relation is that in which sector i influences sector j and the latter also influences the former. Those sectors which are reciprocally related are said to belong to the same Strongly Connected Component (SCC). In order to define the hierarchy we must, first, detect which SCCs are present in the Andalusian economy and, second, establish a hierarchy of those sectors which do not belong to any of them.

The steps necessary to establish a hierarchy of sectors are the following:

1. First of all, we must obtain a connectivity matrix (N). This shows the type of connection that exists between the sectors and is therefore a symmetrical matrix. It is obtained from the path matrix as follows:

a) If two sectors i and j are related in at least one direction, that is, i is related to j and/or j is related to i, then they are *1-linked* and the element ij of the connectivity matrix will be $n_{ij} = k_{ij} + k_{ji} + 1$, where k_{ij} are elements of the path matrix.

In this case, there are two different possibilities:

a.1) $k_{ij} = k_{ji} = 1$. This means that sector i is related to j and j is also related to i. i and j are then *3-connected* and $n_{ij} = 3$.

a.2) If $k_{ij} + k_{ji} = 1$, then sectors i and j are related in one direction only, thus being *2-connected*; therefore $n_{ij} = 2$.

b) If $k_{ij} + k_{ji} = 0$, then sectors i and j are unrelated, thus being *0-connected*; therefore $n_{ij} = 1$.

c) In any other case, $n_{ij} = 0$.

2. Secondly, once the connectivity matrix has been obtained, we must detect the SCCs. Two sectors i and j belong to the same SCC if i is related to j and j is related to i, that is, if the relationship between them is reciprocal and the element of the connectivity matrix is $n_{ij} = 3$.

3. Finally, we must establish different levels in the hierarchy. Level 1 (L1) will include the *isolated* or *source* sectors[9] of the resulting graph, once the SCC has been identified. Level 2 (L2) will include the isolated or source sectors of the graph which results from

[9] In Graph terminology, a *source sector* is that which influences other sectors but is not influenced by any sectors.

eliminating sectors belonging to level 1, namely, those sectors which are influenced only by sectors on level 1.

According to the classification of coefficients discussed above, we can distinguish between two different hierarchies, which are represented in graphs G5 and G10, respectively[10]. Hierarchical graphs should be interpreted as follows. The sectors located at the base of the pyramid are those potentially more influential on the water consumption of the rest of sectors, since their demands influence those sectors.

Hierarchical structure G5 is that which best illustrates sectoral water consumption in the Andalusian economy. The most relevant sectors are Food and Agriculture Industry (14) and Hotel and Catering Trade (22), located at the base of the pyramid, these being the sectors which purchase the greatest quantities of water. Regarding these sectors, there seems to be a contradiction in the graph: Food and Agriculture Industry (14) buys a greater quantity of water than Hotel and Catering Trade (22), but 14 is nonetheless placed on a higher level. This is due to the fact that 14 not only buys more water than 22, but it also sells water to 22. Therefore, part of the water consumed by Food and Agriculture Industry must be allocated to Hotel and Catering Trade. This sector does not sell water to any other sector, thus closing the water circuit.

It is also noticeable that Food and Agriculture Industry (14) buys most of its products (89%) from agricultural sectors. In a similar fashion, Hotel and Catering Trade (22) buys products from agricultural sectors (76%) and from Food and Agriculture Industry (24%). It can be then concluded that these three sectors – agricultural sectors, Food and Agriculture Industry and Hotel and Catering Trade – are those which consume the greatest amounts of water in the economic system, directly in the case of agricultural sectors, and indirectly in the other two cases.

The position of Construction (20) in the hierarchical graph G5 is also worth noticing. This sector is placed on level 2, that is, it is not located at the base of the graph; however, its influence with relation to purchases is positively relevant, as shown in the hierarchical graph G10. This fact is particularly remarkable since Construction is one of the most dynamic sectors in the Andalusian economy. Although the sector's relevance can be attributed to current economic trends rather than to structural reasons, it actually exerts a decisive influence on water consumption.

[10] No hierarchies are defined for graphs G and G1 because all their sectors belong to the same SCC.

Indirect consumption of water by Textiles and Apparel (15) is also remarkable. This sector is placed on level 2 both in graph G5 and in graph G10, and its demand is exclusively directed to Industrial Plants (4).

To sum up, Food and Agriculture Industry (14), Hotel and Catering Trade (22), Construction (20), and, to a lesser extent, Textiles and Apparel (15), play a crucial role in the Andalusian economy, in terms of production and employment; however, they are also the sectors which consume the greatest amounts of water. For this reason, an economic policy which supports these sectors might be said to be adequate if only economic variables are taken into account, but it might be thought not to be so from an environmental point of view, since supporting those sectors means encouraging the consumption of a natural resource which is quite scarce in the region.

4. Conclusions and implications for economic policy

Some interesting conclusions can be drawn from the analysis presented in this paper. We believe that the most relevant features of this research are, on the one hand, the application of a mixed methodology to the study of intersectoral relationships and, on the other hand, the implications for economic policy.

Firstly, it has been shown that a mixed methodology, combining the extended Input-Output model and Graph Theory, is adequate to analyze the relationships between the production structure and the consumption of natural resources. This methodology allows both direct and indirect relationships to be examined and detailed. In addition, it enables us to establish a sectoral hierarchy by means of which we can determine how dependent on water the different sectors are. Finally, it also shows the water circuit within the production system.

Secondly, the water circuit within the regional economy can be defined. In the Andalusian economy, water starts 'circulating' from agricultural sectors, then passes through sectors such as Construction and Textiles and Apparel, and finally reaches Food and Agriculture Industry and Hotel and Catering Trade. Despite the fact that a considerable number of relationships are established within this circuit, it can be seen that most of them are irrelevant, and that those which are really significant because of their intensities are restricted to very few sectors, among which the three sectors just mentioned are the most remarkable. This fact has to be taken into account when designing an economic policy oriented towards water conservation. Our third conclusion is then that planning efforts should not be aimed at *all* production sectors, but they should only focus attention on those sectors which carry out almost 90% of all water transactions at a regional level.

Fourthly, there are sectors which are massive consumers of water but that are rarely regarded as such. Again, these sectors are Food and Agriculture Industry, Construction, Textiles and Apparel, and Hotel and Catering Trade. In spite of the fact that their direct consumption is not particularly high, their indirect consumption is certainly so. Therefore their demands increase the water shortage in the region and could also endanger economic stability, as they foster the economy's dependence on water. Policy planners must take this high indirect consumption into account and must focus their attention on these three sectors, once they realize that agricultural sectors are not the only ones which consume great amounts of water.

Finally, some of the questions posed at the beginning of this paper can now be answered. Recall that we wondered whether the water consumption of Andalusian production sectors could negatively influence water conservation and economic soundness. The results obtained point to an affirmative answer. Economic specialization in Andalusia, based on water-consuming sectors which are highly dependent on this natural resource (some of them directly, as agricultural sectors; some of them indirectly, as Food and Agriculture Industry, Construction, Textiles and Apparel, and Hotel and Catering Trade) does not foster conservation of water resources. This situation could threaten the regional economy, since the sectors which consume the greatest amounts of water are precisely those known as the 'driving forces' of the region.

Economic policy planning must therefore take account of consumption of water resources. Environmental aspects such as water consumption should be included in any economic policy, not only because of the effects that water consumption may have on water conservation, but also because of the effects it may have on economic stability. Unfortunately, Andalusian policy planners have not become aware of these facts yet, what explains why the regional economy is based on sectors which are highly dependent on water – a dependence that increases water shortage.

Table 1. Matrix of Intersectoral Water Relationships for Andalusia (W) (in thousands of cubic metres).

	SECTORS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Sum
1	Cereals and leguminous plants	291,287	2,297	150	289	180	72,166	1,006	0	359	246	723	504	703	450,624	918	44	759	1,860	201	5,683	2,457	71,142	692	3,355	4,259	911,900
2	Vegetables and fruits	64	834,403	39	36	50	3,701	545	0	186	116	322	269	375	16,453	311	21	199	192	79	2,164	1,298	40,069	364	1,361	3,537	906,155
3	Citrus fruits	25	190	294,140	15	24	682	205	0	74	42	1,106	95	136	6,400	114	8	72	63	29	811	453	13,502	134	552	2,288	321,162
4	Industrial plants	22	112	9	15,562	12	1,829	94	0	41	28	161	49	81	58,062	17,935	49	72	330	100	437	271	6,508	91	273	459	102,589
5	Olive groves	170	860	70	89	170,502	15,669	807	0	280	198	558	400	557	537,551	535	33	356	677	128	3,511	1,928	58,962	542	2,051	3,415	799,845
6	Other agricultural productions (*)	1,102	3,685	202	519	231	147,956	404	0	167	116	253	214	302	86,913	954	24	1,018	3,183	175	5,262	1,113	23,179	314	3,176	1,768	282,231
7	Extractive industry	31	120	14	16	35	116	10,288	0	178	255	749	42	103	759	107	4	69	65	19	1,121	585	407	557	262	388	16,289
8	Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	Metallurgy	61	123	11	23	47	98	63	0	19,491	43	60	240	793	848	106	8	80	6	94	2,740	38	131	34	59	91	25,289
10	Construction materials	1	5	0	0	1	10	24	0	29	1,877	9	21	12	231	4	0	9	8	2	3,278	28	85	9	31	36	5,713
11	Chemicals and plastics	214	1,754	86	133	212	465	539	0	293	88	27,806	128	233	3,147	337	20	219	275	80	2,587	251	998	287	613	333	41,100
12	Machinery	1	2	1	0	1	2	1	0	7	2	2	613	10	17	3	0	1	1	0	32	7	3	2	4	20	733
13	Transportation material	0	0	0	0	0	3	1	0	1	0	1	1	2,436	5	1	0	0	0	0	5	5	3	8	36	4	2,512
14	Food and agriculture industry	9	44	4	4	4	795	41	0	14	10	28	20	28	27,283	27	2	18	34	7	178	98	2,993	28	104	173	31,947
15	Textiles and apparel	1	3	0	0	0	34	1	0	2	1	3	1	5	44	4,416	8	3	2	1	9	14	38	7	9	18	4,621
16	Footwear and Leather products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	255	0	0	0	0	6	0	0	1	1	266
17	Lumbre industry	1	8	1	1	1	17	6	0	3	4	5	5	29	67	2	0	2,456	4	2	212	20	13	5	40	12	2,913
18	Paper, printing and publishing	7	37	3	3	5	185	60	0	158	163	102	134	97	1,801	125	43	44	16,614	250	802	492	383	213	800	1,186	23,708
19	Miscellaneous manufacturing	0	0	0	0	0	4	1	0	0	1	0	0	5	9	3	0	1	0	1,088	4	2	2	1	2	9	1,133
20	Construction	3	21	2	1	3	17	63	0	15	10	20	52	21	86	16	1	10	4	3	16,461	126	105	39	135	138	17,353
21	Trade	11	58	5	5	11	145	130	0	112	36	39	48	107	606	67	4	79	34	11	684	14,270	339	46	133	94	17,073
22	Hotel and catering trade	55	467	48	34	62	458	746	0	254	157	440	369	512	2,494	404	29	245	161	105	2,857	1,761	55,794	495	1,499	1,181	70,626
23	Transportation and comunications	24	93	10	10	23	214	254	0	136	117	174	103	160	1,070	158	10	86	80	36	1,298	982	415	5,199	481	438	11,571
24	Sales related services	25	150	13	11	26	215	612	0	252	121	239	209	505	1,333	232	16	208	124	50	1,778	2,298	1,237	518	20,926	1,639	32,739
25	Non-sales related services	1	4	0	0	1	3	6	0	0	0	0	0	0	6	0	0	0	0	0	1	1	1	0	0	23,323	23,349
	Sum	293,044	844,090	294,780	16,754	171,430	244,786	15,897	0	22,052	3,630	32,804	3,515	7,212	1,195,809	26,774	580	6,003	23,717	2,463	51,915	28,506	276,309	9,585	35,901	44,809	3,652,816

Source: created by the author.

Table 2. Matrix of technical coefficients (Q).

	SECTORS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	Cereals and leguminous plants	0.04	0.00	0.00	0.00	0.00	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.02
2	Vegetables and fruits	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.01	0.11
3	Citrus fruits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.00	0.01	0.08
4	Industrial plants	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	2.12	4.04	0.05	0.01	0.01	0.07	0.00	0.00	0.00	0.00	0.00	0.00
5	Olive groves	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Other agricultural productions (*)	0.00	0.00	0.00	0.01	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.79	0.03	0.00	0.33	0.17	0.06	0.20	0.00	0.22	0.00	0.10	0.02
7	Extractive industry	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.01	0.11	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.00	0.01	0.02	0.03	0.00	0.09	0.01	0.01
8	Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Metallurgy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.02	0.00	0.34	0.29	0.02	0.02	0.03	0.03	0.00	0.08	0.15	0.00	0.00	0.00	0.00	0.00
10	Construction materials	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00
11	Chemicals and plastics	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.01	0.03	0.10	0.14	0.07	0.04	0.03	0.06	0.07	0.01	0.06	0.12	0.00	0.01	0.04	0.02	0.01
12	Machinery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Transportation material	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Food and agriculture industry	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
15	Textiles and apparel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Footwear and Leather products	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	Lumbre industry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.05	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
18	Paper, printing and publishing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.08	0.00	0.18	0.02	0.05	0.02	0.15	0.01	0.05	0.21	0.02	0.02	0.00	0.03	0.03	0.04
19	Miscellaneous manufacturing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Construction	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01
21	Trade	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.00	0.06	0.04	0.02	0.01	0.01	0.03	0.00	0.01	0.03	0.01	0.00	0.01	0.00	0.00
22	Hotel and catering trade	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.01	0.06	0.01	0.53	0.17	0.06	0.07	0.10	0.08	0.01	0.08	0.13	0.10	0.00	0.08	0.07	0.04
23	Transportation and comunications	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.05	0.01	0.14	0.05	0.03	0.03	0.03	0.03	0.00	0.03	0.06	0.06	0.00	0.03	0.02	0.01
24	Sales related services	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.01	0.04	0.01	0.27	0.17	0.03	0.04	0.05	0.07	0.01	0.03	0.07	0.14	0.02	0.08	0.06	0.06
25	Non-sales related services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Created by the author.

Table 3. Matrix of distribution coefficients (L).

	SECTORS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	Cereals and leguminous plants	0.32	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.08	0.00	0.00	0.00
2	Vegetables and fruits	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
3	Citrus fruits	0.00	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.01
4	Industrial plants	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
5	Olive groves	0.00	0.00	0.00	0.00	0.19	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00
6	Other agricultural productions (*)	0.00	0.01	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.08	0.00	0.01	0.01
7	Extractive industry	0.00	0.01	0.00	0.00	0.00	0.01	0.63	0.00	0.01	0.02	0.05	0.00	0.01	0.05	0.01	0.00	0.00	0.00	0.00	0.07	0.04	0.02	0.03	0.02	0.02
8	Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Metallurgy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.01	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.01	0.00	0.00	0.00
10	Construction materials	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.33	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.57	0.00	0.01	0.00	0.01	0.01
11	Chemicals and plastics	0.01	0.04	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.68	0.00	0.01	0.08	0.01	0.00	0.01	0.01	0.00	0.06	0.01	0.02	0.01	0.01	0.01
12	Machinery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.84	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.00	0.00	0.01	0.03
13	Transportation material	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
14	Food and agriculture industry	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.09	0.00	0.00	0.01
15	Textiles and apparel	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.96	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
16	Footwear and Leather products	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
17	Lumbre industry	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.84	0.00	0.00	0.07	0.01	0.00	0.00	0.01	0.00
18	Paper, printing and publishing	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.08	0.01	0.00	0.00	0.70	0.01	0.03	0.02	0.02	0.01	0.03	0.05
19	Miscellaneous manufacturing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.96	0.00	0.00	0.00	0.00	0.00	0.01
20	Construction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.01	0.01	0.00	0.01	0.01
21	Trade	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.04	0.84	0.02	0.00	0.01	0.01
22	Hotel and catering trade	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.04	0.01	0.00	0.00	0.00	0.00	0.04	0.02	0.79	0.01	0.02	0.02
23	Transportation and comunications	0.00	0.01	0.00	0.00	0.00	0.02	0.02	0.00	0.01	0.01	0.02	0.01	0.01	0.09	0.01	0.00	0.01	0.01	0.00	0.11	0.08	0.04	0.45	0.04	0.04
24	Sales related services	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.01	0.00	0.01	0.01	0.02	0.04	0.01	0.00	0.01	0.00	0.00	0.05	0.07	0.04	0.02	0.64	0.05
25	Non-sales related services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Source: Created by the author.

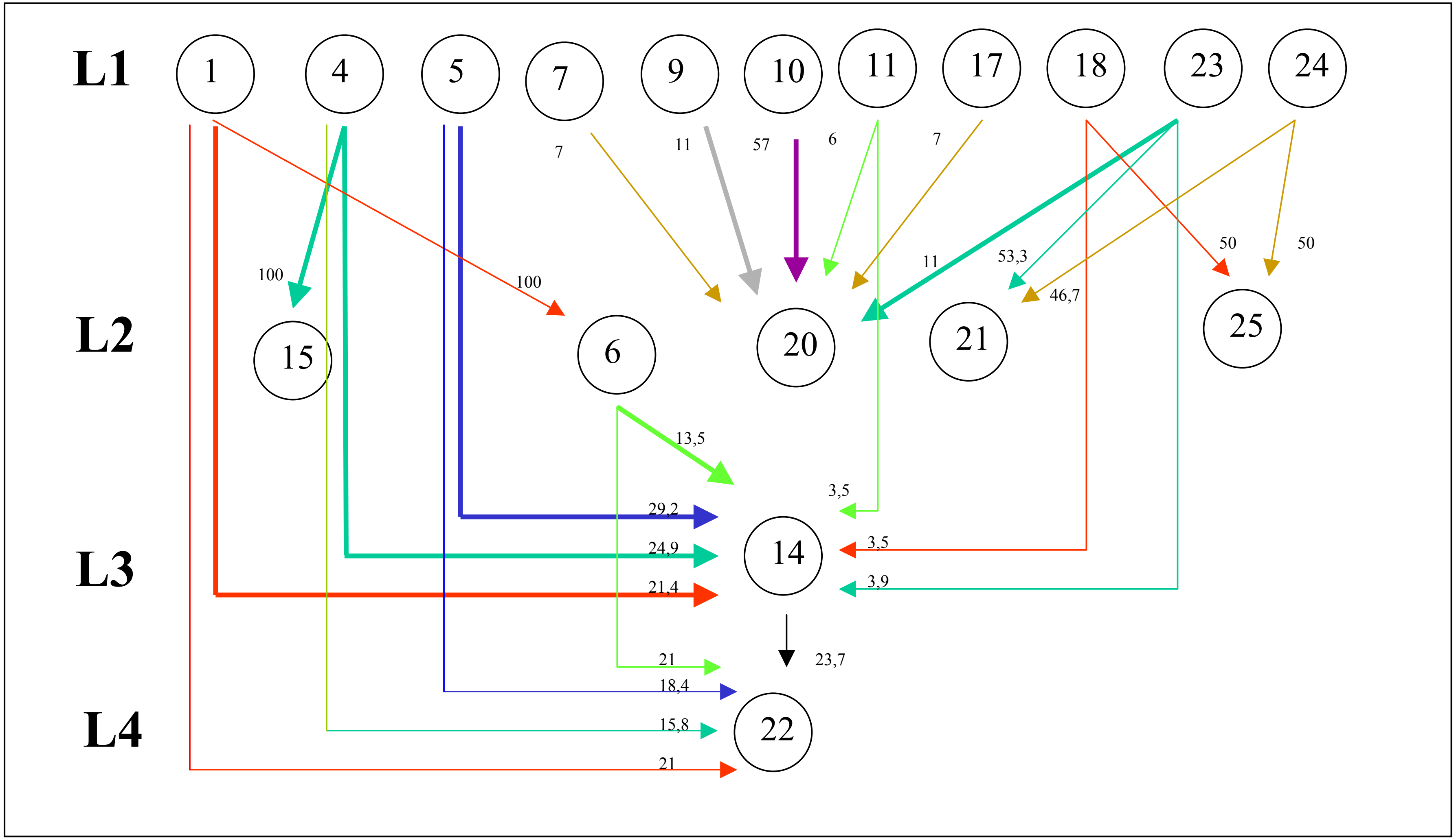
Table 4. Semidegrees and Net Dependency Index (NDI) of graphs G, G1, G5, and G10.

SECTORS	G				G1				G5				G10			
	S(+)	s(-)	s	NDI	s(+)	s(-)	s	NDI	s(+)	s(-)	s	NDI	s(+)	s(-)	s	NDI
1 Cereals and leguminous plants	23	20	43	0.9	4	1	5	0.3	4	1	5	0.3	2	1	3	0.5
2 Vegetables and fruits	21	24	45	1.1	3	3	6	1.0	1	1	2	1.0	1	1	2	1.0
3 Citrus fruits	22	19	41	0.9	3	1	4	0.3	1	1	2	1.0	1	1	2	1.0
4 Industrial plants	24	18	42	0.8	5	1	6	0.2	4	1	5	0.3	3	1	4	0.3
5 Olive groves	23	20	43	0.9	4	1	5	0.3	3	1	4	0.3	2	1	3	0.5
6 Other agricultural productions (*)	24	24	48	1.0	7	7	14	1.0	3	2	5	0.7	2	1	3	0.5
7 Extractive industry	24	24	48	1.0	11	5	16	0.5	2	1	3	0.5	1	1	2	1.0
9 Water	24	23	47	1.0	4	4	8	1.0	2	1	3	0.5	2	1	3	0.5
10 Metallurgy	24	23	47	1.0	4	3	7	0.8	2	1	3	0.5	2	1	3	0.5
11 Construction materials	24	23	47	1.0	8	3	11	0.4	3	1	4	0.3	1	1	2	1.0
12 Chemicals and plastics	24	23	47	1.0	7	2	9	0.3	1	1	2	1.0	1	1	2	1.0
13 Machinery	19	23	42	1.2	2	5	7	2.5	1	1	2	1.0	1	1	2	1.0
14 Transportation material	24	24	48	1.0	3	18	21	6.0	2	9	11	4.5	1	6	7	6.0
15 Food and agriculture industry	24	23	47	1.0	1	2	3	2.0	1	2	3	2.0	1	2	3	2.0
16 Textiles and apparel	20	17	37	0.9	2	1	3	0.5	1	1	2	1.0	1	1	2	1.0
17 Footwear and Leather products	24	23	47	1.0	4	1	5	0.3	2	1	3	0.5	1	1	2	1.0
18 Lumbre industry	24	23	47	1.0	8	2	10	0.3	3	1	4	0.3	1	1	2	1.0
19 Paper, printing and publishing	19	23	42	1.2	1	2	3	2.0	1	1	2	1.0	1	1	2	1.0
20 Miscellaneous manufacturing	24	23	47	1.0	1	13	14	13.0	1	8	9	8.0	1	4	5	4.0
21 Trade	24	23	47	1.0	4	8	12	2.0	1	3	4	3.0	1	1	2	1.0
22 Hotel and catering trade	24	24	48	1.0	7	15	22	2.1	1	6	7	6.0	1	1	2	1.0
23 Transportation and comunications	24	23	47	1.0	14	3	17	0.2	4	1	5	0.3	2	1	3	0.5
24 Sales related services	24	23	47	1.0	9	9	18	1.0	5	1	6	0.2	2	1	3	0.5
25 Non-sales related services	6	24	30	4.0	1	7	8	7.0	1	3	4	3.0	1	1	2	1.0
Sum	537	537	1074	26.9	117	117	234	44.8	50	50	100	37.1	33	33	66	28.8
Average	21	21	42	1	5	5	9	1.8	2	2	4	1.5	1	1	3	1.2

Source: Created by the author.

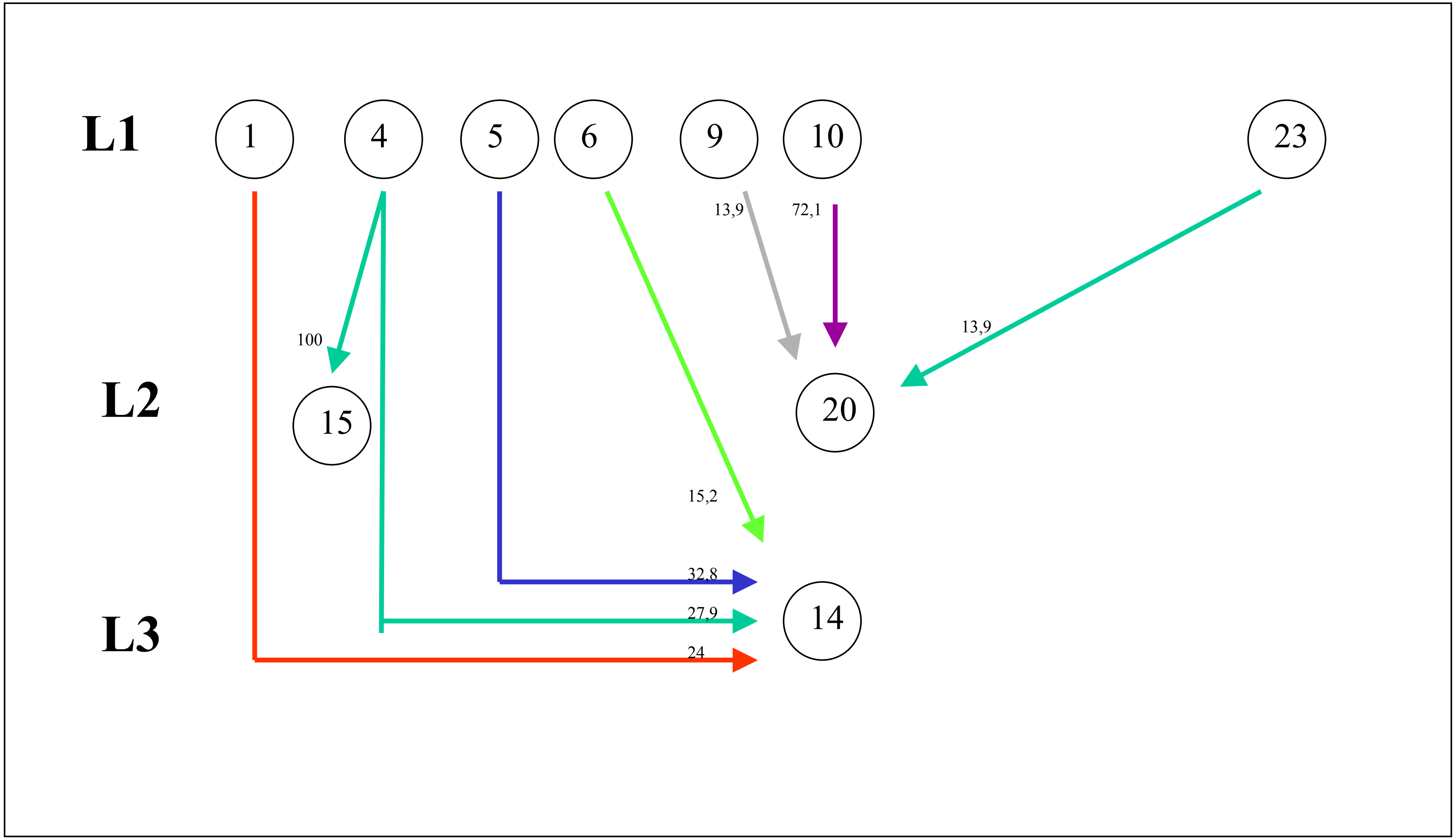
s: total semidegree of the sector, obtained as the sum of the two previous ones,

Figure 1. Hierarchical Graph H5, derived from graph G5.



Source: created by the author
For simplicity´s sake, isolated sectors on level 1 have not been included in the graph. These serctors are: 2, 3, 12, 13, 16, 19
The figures represent each sector´s purchases <u>with relation to total purchases</u>.

Figure 2. Hierarchical Graph H10, derived from graph G10.



Source: Created by the autor.

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