Groupe de Recherche en
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Construction of linkage indicators of greenhouse gas emissions for Aquitaine region

Jean-Christophe MARTIN

Patrick POINT

GREThA, CNRS, UMR 5113
Université de Bordeaux

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GRETHA UMR CNRS 5113
Université Montesquieu Bordeaux IV
Avenue Léon Duguit - 33608 PESSAC - FRANCE
Tel : +33 (0)5.56.84.25.75 - Fax : +33 (0)5.56.84.86.47 - www.gretha.fr

Construction d'indicateurs d'effets d'entrainement pour les émissions de gaz à effet de serre de la région Aquitaine

Résumé

Ce papier propose de construire des indicateurs d'effets d'entrainement sur les émissions de gaz à effet de serre (GES) dans la région Aquitaine en recourant à la notion d'intégration verticale avec une présentation du résultat sous forme de bloc. Du fait que la comptabilité régionale en France est peu développée, nous avons dû construire un tableau entrées-sorties (TES) pour la région Aquitaine avec un inventaire associé des émissions de GES. La méthode de construction du TES va influencer à la fois la fiabilité et la richesse des résultats.

Mots-clés : tableaux entrées-sorties régionalisés, quotients de localisation, émissions de gaz à effet de serre, indicateurs d'effets d'entrainement

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Abstract

This paper proposes to construct linkage indicators of greenhouse gas (GHG) emissions for the Aquitaine region of France by using the notion of vertical integration with a presentation of results in the form of block. Because of poor regional accounting in France, we had to construct an input-output table for the Aquitaine region with a GHG emissions inventory associated. Method of construction of input-output table will affect both reliability and richness of results.

Keywords: regionalized input-output table, quotients of localization, greenhouse gas emissions, linkage indicators

JEL : C67, R15, E2, Q4, Q54

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1 Introduction

In order to fight against climate change, France has been committed to reduce its greenhouse gas (GHG) emissions by four for 2050. The government is aware of some difficulties to reach its GHG emissions reduction target without an active participation of territorial collectivities and, particularly, of regions. The region of Aquitaine has implemented a climate plan in order to avoid 2 883 $ktCO_2eq$ per year for 2007-2013, that is 13% of its GHG emissions of 2008. But, French regions need environmental studies in order to guide efficiently in the implementation of their climate plans.

A policy against climate change needs to select main sectors having important linkages on regional GHG emissions. Input-output (IO) model is relevant for this issue because it incorporates the complexity of interindustrial trade with a detailed sectoral study (Leontief, 1986). Moreover, this model has been extended to environment (Leontief, 1970) and particularly to GHG emissions (Proops et al., 1993). Different research works show the interest of the IO modelling for environmental issues (Hawdon and Pearson, 1995 ; Zhang and Folmer, 1998 ; Munksgaard et al., 2005 ; Berck and Hoffman, 2002). Leontief model is a demand-driven model. So, emissions are entirely attributable to final demand (consumption-based accounting). This accounting method enables to evaluate GHG emissions along the chains of production (Widermann, 2009). The model determines necessary direct and indirect GHG emissions to satisfy the final demand. The rediscovery of this analysis for regional studies in relation to the environment could be explained for different reasons. First, countries to respect their commitment taken in the Kyoto Protocol have to implement climate plans at different geographical levels (international, national, regional and local). Then, IO model is a good trade-off between the relevance of results and the specific regional constraints on data (West, 1995). We could cite for instance the work of Mc Gregor et al. (2008) concerning their studies on GHG emissions at regional level. Finally, the increasing popularly of this model is explained by a more powerful capacity of computer to handle matrix inversion with large datasets (Loveridge, 2004). This model has some limitations because of linearity assumption and no supply-side constraints (See Lenzen 2003, West 1995). However, the linearity assumption enables to the model be tractable (Hawdon and Pearson, 1995).

Three types of studies are possible thanks to IO analysis: to make descriptive studies, to contribute to impacts assessments and to construct some simulations. In this paper, we restrict to a descriptive study. We will evaluate both backward and forward GHG emissions of each sector for the Aquitaine region. We use the methodology of vertical integration presented by Pasinetti (1977) and developed by Duarte et al. (2002) and Sanchez-Choliz and Duarte (2003a, 2003b, 2005). It is a relevant method for the studies on sectors interdependence. It overcomes the weaknesses of Hirschman-Rasmussen indices (1958), highly used in literature (see Sanchez-Choliz and Duarte, 2003a). It has the interest to discriminate intersectoral demand with final demand by breaking down GHG emissions of sectors on four components: net backward component, net forward component, internal component and mixed component. Although the authors used this methodology for water study, this analysis could also be applied to GHG emissions study. Furthermore, Sanchez-Choliz and Duarte (2005) show the results in a sectors block enabling both a synthetic presentation of results and avoiding aggregation bias.

But the carrying out of this study requires having an input-output table (IOT) with a GHG emissions inventory associated. However, as the national institute for statistics and economic studies (INSEE) does not construct an IOT at regional level, we had to estimate one. In parallel, we construct a GHG emissions inventory consistent with the regional IOT nomenclature.

We first explain the methodology of construction of IOT for the Aquitaine region with GHG emissions inventory associated. The construction of regional data will lead then to study the role of sectors interdependence for regional GHG emissions.

2 presentation of technique of regionalizing national input-output table

Because of poor regional accounting in France, INSEE is not able to product an IOT at regional level. We had so to estimate one. We will explain the main steps to construct a regional IOT.

2.1 Adoption of top-down approach

The construction of IOT for the Aquitaine region must fulfil a double requirement: costless in time and in human resources, and errors from the hypotheses of construction will influence moderately the results of the model though it is difficult to quantify them. Therefore, the methodologies that we will adopt must fulfil these different requirements because the construction of this regional IOT is only a step for environmental studies.

Two traditional methods exist to construct regional IOT: "bottom-up method" and "top-down" method. The first method uses directly regional data thanks to surveys and interviews whereas the second method consists of regionalizing national IOT using statistical indicators.

From the theoretical point of view, the first method is preferable because it enables to incorporate well regional specificities. The techniques of production are differentiated between regions. A specific nomenclature is elaborated in order to take account regional productive structure. In USA, one of the most famous examples is the construction of IOT for the State of Washington for the following years 1963, 1969, 1972, 1982 and 1987 by Chase, Bourque and Conway (1993). Although the Anglo-Saxon literature is scarce, it does not exclude interesting experiences on foreign countries, rarely writing in English language (Boomsma and Oosterhaven, 1992). For instance, in Spain, the regional institutes for statistics have constructed IOT based on surveys. Cortinas and Vicente (2009) show the method of construction of IOT for Castilla la mancha, one of Spanish provinces. The construction of regional IOT in France by bottom-up method was introduced by Bauchet for the Lorraine region in 1955. After, each French region was concerned by this work between 1955 and 1970. Concerning the Aquitaine region, we could cite the works of professor Jouandet-Bernadat (1965) thanks to the help of members of the institute of the regional economics of South-West (IERSO). But, the constitution of regional IOT was often incomplete because these IOT were more devoted to study the regional productive structure than to make forecasting and simulation studies by using input-output analysis (Ousset J, 1975).

The relatively low use of this method comparatively to top-down method is explained by its different limitations. Richardson (1972) explains them. First, survey requires obtaining complex information. Then, the response rates are very low. Finally, there are the dangers to obtain incorrect information. Because of these different difficulties, adjustments processes are so necessary to implement in order to verify supply-use equilibrium of products. This work is costly because it needs considerable financial and human resources. It is a research project carried out by a research institute or a research team. Mattas et al. (1984) estimate that cost for the construction of the IOT by "bottom-up" method are twenty higher than "top-down" method.

"Top-down" method is more relevant for this issue. It aims to regionalize at lower cost the different national input-output components by using available statistical indicators. It avoids inherent difficulties of surveys. This method is largely explained in Miller and Blair (1985).This model assumes that production techniques are relatively stable within a nation. Importations enabling to calculate regional technical coefficients are estimated by location quotients, which a lot of research in regional economics are focus on. Miller and Blair (1985) indicated the main location quotients[1] . Recently, some improvements could be made for "weighted" location quotients (Flegg

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[1] simple location quotient, purchases-only location quotients, cross-industry quotients, supply-demand pool approaches, fabrication effects and regional purchase coefficients

and webber, 1997). Literature about the construction of regional IOT with top-down method developed by Isard (1951) is more abundant because it enables to construct rapidly and at least cost. Since 1970, the Bureau of Economic Analysis (BEA) has developed a methodology to estimate regional multipliers, named RIMS (Regional Input-output Modelling System). Regional IOT are estimated from national IOT, which are then adjusted thanks to regional data enabling to integrate some regional specificities. The RIMES model is currently used in USA to assess impacts of a project at regional level. In France, one of the most famous works comes from Courbis and Pommier (1979) thanks to the team of researchers at the laboratory of GAMA. France was divided into five big regions where an IOT for each region was constructed thanks to many different statistical data of INSEE. These regional IOT were consistent with the national IOT: the sum of these regional IOT constitutes the national IOT. They built a very developed and rigorous methodology in order to regionalize national IOT. This work was involving an important mobilization of members of the laboratory of GAMA during four years (from 1972 to 1976). The construction of regional IOT constituted the basis of REGINA model, with an objective to study national-regional interactions. Concerning the Aquitaine region, Delfaud (1982) built an IOT by top-down method in order to make some forecasting studies by using input-output analysis.

This method has also some limitations because of weak theoretical base (Brand, 1997) and no incorporation of regional specificities. The production function is considered to be homogeneous within a nation (Jouandet-Bernadat, 1967). But this construction method has the interest to be rapid, coherent and operational to an input-output analysis. In order to incorporate better regional specificity, we used some surveys made by the national institute for statistics.

However, the regionalization of a national IOT requires that the national IOT is symmetric and expressed entirely at basic price in order to be compatible with an input-output analysis. This step will enable then to regionalize national IOT for the Aquitaine region.

2.2 The construction of a symmetric national input-output table

The starting point is the national IOT for 2001 in 114 sectors. It is highly recommended to regionalize the most disaggregated national IOT in order avoid the famous problem of aggregation bias (Malinvaud, 1954).

The national IOT as presented by INSEE is not operational to input-output analysis because IOT in 114 sectors is a commodity-by-industry input-output account. INSEE does not estimate a symmetric IOT at this level of aggregation. Furthermore, INSEE doest not discriminate the (domestic and imported) origin of products for the demand of the product and they are entirely expressed in purchasers' prices. We indicate the three steps necessary to construct a symmetric national IOT.

The first step consists of evaluating intermediate and final demand at basic price. The database NOUBA indicates for each component of intermediate and final demand trade margins, transportation margins and taxes for 2002, but not for 2001. We assumed that the share of margins in intermediate and final demand is identical for 2001 and 2002. As soon as we estimated these margins, we reallocated them into the concerned products according to recommendations of Miller and Blair (1985). Transport margins will so be allocated to transport products and trade margins to trade products. We must then subtract taxes. INSEE indicates also for each components of intermediate and final demand the amount of taxes by assuming the share of taxes on intermediate demand is identical. We obtain so an interindustrial transactions table expressed at basic price. But the interindustrial transactions table is still a "commodity-by-industry" matrix.

The second step consists of transforming "commodity-by-industry" transactions table into "commodity-by-commodity" transactions table. Input-output analysis requires to construct a "commodity-by-commodity" transactions table (Miller and Blair, 1985). To make this matrix, two assumptions are possible: the commodity technology assumption or industry technology assumption (Ten Raa and Rueda-Cantuche, 2007). The commodity technology assumption argues that industries have the same input structure. On contrary, industry technology assumption argues that commodities have the same input structure. The commodity technology assumption is preferable from an axiomatic point of view (Jansen and Ten Raa,1990) but it implies negative technical coefficients. Some methods have been developed to solve this problem (Almon, 2000). This assumption is the most used (Eurostat 2008, Bohlin and Widell, 2006). On contrary, the industry technology assumption has the interest to avoid negative technical coefficients (De Mesnard, 2004a) ant it is more coherent with a circuit approach (De Mesnard, 2004b). This assumption has been selected for the construction of French symmetric IOT (Braibant, 2006) and for some other IOT (Fritz et al., 2003). We followed the recommendations of De Mesnard (2004b) and Braibant (2006) with a construction of a commodity-by-commodity national IOT by using the industry technology assumption. A supply matrix is essential to make this transformation. To obtain a commodity-by-commodity transaction table, it is sufficient to multiply the commodity-by-industry transaction table by the transpose of the supply matrix expressed in percentage. The value added is also calculated by using the supply matrix. We obtain so a symmetric input-output table, expressed entirely to basic price.

The third step consists of discriminating domestic and imported origins for intermediate and final demand. This step is crucial to compute national technical coefficients. This result will use after to compute regional technical coefficients. INSEE accounts the importations of products when it comes into the national territory by the customs services without worrying about the destination of products. INSEE makes some estimation about the destination of imported products but they are not willing to communicate it because of too many uncertainties in their results. Because of not sufficient statistical data, importation will be allocated to intermediate and final demands on the basis of output coefficients. This assumption implies that the share of imported products of each components of intermediate and final demand is identical for each sector.

After making these different calculations, we could obtain a national symmetric commodity-by-commodity transaction table, operational to an input-output analysis. We must now regionalize different components of the national IOT.

2.3 Estimation of regional added value

INSEE estimates the added values at regional level with a high level of aggregation (14 sectors). It is essential to estimate these added values in more disaggregated level, that is in 114 sectors. The estimated values from INSEE will be served to quantify errors estimations.

A Traditional way to estimate the added value is to use top-down method by assuming that the labour productivity of each sector is similar whatever the geographical level within a nation (Schaffer and Chu, 1969 ; Kronenberg, 2009). The regional added value is calculated by making the ratio of national added value to national employed people in sectors i that we multiply then by regional employed people in this sector. However, this calculation requires data on employed people by sector at regional level. In France, there are two available datasets indicating the number of employed people by sector: the population census and data from UNEDIC[2] (L'Union Nationale interprofessionnelle pour l'Emploi Dans l'Industrie et le Commerce).

The first dataset is the most exhaustive because it is a result of compulsory survey for national population. But it is taken every 7 years. The population census closest to 2001 is 1999. The second dataset is taken every year. It accounts the number of salary with a detailed geographical area. But are excluded salaried employee of State and territorial collectivities, employee of embassy, foreign consulate and international organization, salaried employee of farm sectors,

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[2] the institution that manages the funds of the "Assurance ch?mage" and that pays unemployment benefits

home employee, employee of public companies whose activity is both industrial and commercial, local government control, some companies of mixed economy and showbusiness intermittent workers.
The table 1 indicates the coverage rate of the data from UNEDIC compared to data from the population census.

Table 1: coverage rate of the data of UNEDIC compared to data of population census (PC), expressed in the nomenclature in 16 sectors (NES 16)

Code	Name of sectors	UNEDIC/PC
EA	Agriculture, forestry, fishing	1%
EB	Food-processing industry	79%
EC	Consumer goods industry	87%
ED	Automotive industry	99%
EE	Capital goods industry	97%
EF	Intermediate goods industry	91%
EG	Energy	62%
EH	Construction	79%
EJ	Trade	86%
EK	Transports	75%
EL	Financial activities	63%
EM	Real estate activities	95%
EN	Business services	78%
EP	Services for individuals	40%
EQ	Education, health care and social services	31%
ER	Administration	19%
	Total	56%

Workforce accounted by UNEDIC covers only 56% of total workforce. The relatively low rate masks strong inequalities. The coverage rate is very strong for industry sector (from EC to EF) with a rate higher than 90% whereas they are very low for agriculture sector (EA) with a coverage rate of 1%. They are quite mixed for services except for trade and real estate activities.
It is also possible to make more complex the top-down method by incorporating differences of productivity for some sectors between the nation and the region. The size of establishment can explain the productivity differences: an establishment with a bigger size enables to benefit some economies of scale (Hufbauer, 1970). These differences of productivity can be calculated by payments per employee. The database ALISSE of INSEE indicates exhaustively for industry sector the amount of payments associated with the amount of workforce for each French region. It is straightforward to compute according to nomenclature in 114 sectors (NES 114) for industry sector the difference of payments per employee between the nation and the region. To compute the total payment for the region for each sector, it is sufficient to multiply the regional payment per employee with the workforce from the population census updated by data from UNEDIC. The regional added value was calculated from the national added value in the proportion to the payments. As this method gives better results for industry sectors, it will be selected them.
To sum up, the table 2 shows the used database and methods to estimate regional added value for 114 sectors.

These results could be compared with the estimations made by INSEE. We so calculated a error rate ρ for each 14 sectors, equal to ratio of our estimated added value to the added value estimated by INSEE. A value close to 1 for a sector indicated that the estimation for this sector is correct. If, for a sector, the ratio value is higher than 1 so the added value was overestimated. On

Table 2: the used database and method to estimate regional added value)

Sectors	The used database	The used method
Agriculture, Forestry, Fishing	The population census (CS) of 1999	Top-down
Industry	CS 1999, updated by UNEDIC database	Payments
Construction	CS 1999	Top-down
Energy	CS 1999	Top-down
Private services	CS 1999	Payments
Public services	CS 1999	Top-down

contrary, if the ratio value is lower than 1 so the added value was underestimated. The average of error rate for the 14 sectors is 0.989. The added values were globally well estimated because the error rates were between 0.95 and 1.05. However, the added values were underestimated and overestimated respectively for financial and real estate activities ($\rho = 0.88$) and services for individuals ($\rho = 1.12$). These rates ρ were used to adjust our estimated added values in order to be consistent with the database of INSEE.

The estimated added value will lead to compute the production and the intermediate consumption for each sector.

2.4 Estimation of production and intermediate consumptions

The estimation of production and intermediate consumptions comes from the information on the production process of sectors. The technical coefficients, indicating the share of intermediate consumption in the production, indicated the production process of sectors. In practical terms, there is no survey in France indication information on production process of regional establishments. The top-down method assumes that technical coefficients are identical between the nation and the region. Thanks to this information and the amount of the added value of sectors, production and intermediate consumptions are straightforward computed.

We have so an estimated interindustrial transaction table and a production account table for each sector.

2.5 Estimation of production and intermediate consumptions

It is important to estimate the regional technical coefficients in order to compute the share of domestic and imported intermediate consumption. Round (1978) indicated the general methodology to estimate regional technical coefficients(a_{ij}^R) from location quotients. They are calculated by multiplying the technical coefficients (a_{ij}) with their importation rates (m_{ij}) as indicated by the formula below :

$$a_{ij}^R = m_{ij}.a_{ij} \tag{1}$$

For regional analysis, it is important to note that importation rate incorporates both national importation rate (importation comes from foreign countries) and regional importation rate (importation comes from other regions within a nation). We show below the methodology of estimation of the two types of importation rate.

Concerning the national importation rate, we assumed that they are stable within a nation whatever the region. They are calculated from national IOT et they are assumed to be identical for each seller sectors i whatever the destination between the different sectors j and the final demand.

Concerning regional importation rate, a lot of research works are focus on their estimation because of missing data on interregional trade. For instance, Leontief and Strout (1963) have developed the gravity model to estimate the trade of products between different regions. Whereas the model is satisfying from the theoretical point of view, it is difficult to implement it. Input-output economists prefer to use the location quotients to estimate regional technical coefficients (Miller and Blair, 1985).

The most used location quotient is the simple location quotient (SLQ). However, one of limitation of SLQ is only determined by the relative size of the supplying sector and the relative size of the region. A lot of research works on the estimation of a regional IOT was devoted to make more complex simple location quotient by calculating "weighted" location quotient leading to estimate more accurately importations. For instance, Flegg and Webber (1995, 1997) has elaborated an location quotient named FLQ enabling to incorporate the three factors listed by Round (1978): the relative size of the supplying sector i, the relative size of the purchasing sector j, and the relative size of the region. Different empirical works (Tohmo, 2004 ; Flegg and Tohmo, 2008) show an important progress to estimate importation with a reduction of errors estimation of importations. Flegg and Webber (1997) chose cross-industry location quotients (CILQ) as the foundation of FLQ. CILQ incorporates the relatively supplying sector and the relatively purchasing sector. This location quotient, more theoretical satisfying than SLQ, gives a worse result. It implies an overestimation of regional technical coefficients (Tohmo, 2004). Flegg and Webber (1997) have adjusted by incorporating the relative size of the region though the coefficient λ. The location quotient is calculated as follow:

$$FLQ_{ij} = CILQ_{ij}.\lambda \text{ with } \lambda = [\log_2(1 + \frac{VAB^{AQUI}}{VAB^{FR}})]^{\delta} \tag{2}$$

Flegg and Webber (1997) advise to estimate econometrically. For the case of missing regional data, as in our case, they advise to take $\delta = 0.3$. The regional technical coefficients (a_{ij}^{R}) are computed by the equation below:

$$a_{ij}^{R} = \begin{cases} a_{ij}^{N} & \text{if } FLQ_{ij} \geq 1 \\ \\ a_{ij}^{N}.(FLQ_{ij}) & \text{if } FLQ_{ij} < 1 \end{cases} \tag{3}$$

where a_{ij}^{N} is the national technical coefficients computed in the national IOT. We remain to estimate the components of the final demand by distinguishing the domestic and imported origins.

The final demand must be estimated as the supply-demand equilibrium of products is always checked.

$$P + M = Z.i + FC + GCF + X \tag{4}$$

Where P, M, FC, GCF, X, Z and i are respectively vectors of production, importations, final consumption, gross capital formation and exportations, matrix of intermediate consumption, and vector composed only of 1.

We first explain the methodology of regionalizing the final consumption and gross capital formation.

We then distinguish the origin of these components. Exportation will be estimated as to verify the supply-demand equilibrium.

2.6 The final consumption

It is important to distinguish the final consumption of households, government and non-profit institutions serving households.

Concerning the final consumption of households, we first assume that consumption per head is identical within a nation for each product. The consumption per head is calculated by the ratio of final consumption of products indicated in the national IOT to the French population. The final consumption of products of regional IOT is found by multiplying these ratios with the regional population. We then integrate some regional specificity concerning the consumption per head by taken again the methodology of Courbis (1979). The consumption per head could be regionalized thanks to the survey of family budget indicating the consumption of 195 products for 8 geographical areas. We have to adjust the nomenclature of this survey with the nomenclature for 114 sectors used by the national IOT.

Concerning the final consumption of government, we must distinguish the individual and collective consumptions. Concerning the individual consumption, it was possible to incorporate some regional specificity by using some regional databases indicated in the table below

Table 3: Databases used to regionalize the individual final consumption of government

Sectors	**Database**	**Source of database**
Pharmaceutical products	Number of pharmacists	Directory of research, studies, evaluation and statistics (DREES)
Education	Number of pupils and students	Ministry of Education
Health care	Number of professional in the health care	DREES
Social services	Available number of places to receive disable people	DREES

Concerning the collective final consumption of government, we assumed that services of States (Justice, Defence,. . .) are equitably distributed to the population without geographical discrimination.

Concerning the final consumption of non-profit institutions serving households, we regionalized the consumption in proportion to the population by assuming that the consumption per head is identical between the regions within the nation.

2.7 The gross capital formation

We have now to estimate the gross capital formation. The different surveys concerning the investments of firms (SESSI database) indicate only the buying of investment goods, but not the selling of investment goods. As we could not obtain the capital matrix indicating the investment goods flow, it was not possible to regionalize it and so to incorporate some regional specificities. Because of statistical constraints, we had to assume that the share of investment goods products by the sector is identical between the nation and the region . We have so an estimation of regional demand for investment goods.

2.8 Estimation of domestic and imported components of final demand (except exportation)

It is important for the construction of our model to distinguish the domestic and import shares of final demand components. The supply-demand equilibrium of regional products is described by the equation below:

$$P = Z^d.i + FC^d + GCF^d + X^d \tag{5}$$

The exponent d indicates the domestic origin of products. In order to verify the supply-demand equilibrium of regional products, we have to discriminate the domestic and imported origins of products. Following the example of the computation of regional technical coefficients, we must distinguish in the importations for the final demand the importations from other region within the nation and the importations from foreign countries.
The importations from the foreign countries for the final demand could be estimated from national IOT by assuming the imported share is identical within the nation.
The importations from the other French regions could be estimated by using the simple location quotients. These quotients are calculated thanks to the following formula.

$$SQL_i = \frac{VAB_i^{AQUI}/VAB^{AQUI}}{VAB_i^{FR}/VAB^{FR}} \tag{6}$$

The calculation of this quotient will allow to estimate the purchases of regionally produced output i by regional final-demand sector f.

$$c_{if}^R = \begin{cases} c_{if}^N.(SQL_i) & \text{if } SLQ_i < 1 \\ \\ c_{if}^N & \text{if } SLQ_i \geq 1 \end{cases} \tag{7}$$

Where c_{if}^N is the purchases of nationally produced output i by regional final-demand sector f estimated in the national IOT. If $SLQ_i \geq 1$, the Aquitaine region is relatively specialised in the production of goods i and it is able to satisfy the final demand without importing from the other French region. The domestic share for goods i is so identical to the national share. On contrary, if $SLQ_i < 1$, the Aquitaine region is not specialised in the production of goods i and it must import goods i from other French regions to satisfy the final demand. The domestic share will be reduced as much as the region is not specialised in the production of this goods.
The domestic final consumption and the domestic gross capital formation produced regionally are computed respectively by these equations:

$$GCF_i^d = c_{i,GCF}^R.GCF \tag{8}$$

$$FC_i^d = c_{i,FC}^R.FC \tag{9}$$

We must now estimate the exportations to finish the construction of the regional IOT.

2.9 Exportation

Exportations are considered as a remainder: it is all the supplying products that are not absorbed by the domestic demand. They lead to verify the supply-demand equilibrium of the products. If the estimations are correct, the exportations of each sector must be positive.
But, for 8 sectors, we found negative exportations. These negative exportations can be interpreted as an insufficient supply to satisfy the domestic demand. The adjustment process will be applied by using the methodology of Miller and Blair (1985). We must reduce regional technical coefficients and the domestic share of the final demand in order to increase the importations and so to raise the supply of products. The importations will increase until to reach a positive importation. The domestic and imported share of exportations will be estimated according to the same methodology presented above by using the equation (7).
We have constructed a regional IOT operational to an input-output analysis. We will give an

example of the using of this IOT by estimating linkage indicators of GHG emissions of different blocks for the Aquitaine region for 2001.

3 Linkage indicators of greenhouse gas emissions

We must first present the GHG emissions function by indicating rapidly the methodology of the construction of GHG emissions inventory associated with the regional IOT. The work will enable us to compute the linkage indicators to estimate the buying and the selling of GHG emissions incorporating in the regional products of each block.

3.1 Construction of the GHG emissions function

The construction of GHG emissions function implies to make before a GHG emissions inventory. For this study, we consider three GHG: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The Kyoto protocol accounts also three other GHG but they are not incorporated in this study because of difficulties to estimate them and a low contribution to total GHG emissions (3%). GHG emissions come from as well as the production process than the household consumption for the fossil fuels. We considered in this paper only GHG emissions from the production process because the aim of this study is to explain GHG emissions of sectors depending on the structure of the regional interindustrial trade.
For this case, GHG emissions come from two sources (Proops et al. 1993)

- Combustion of fossil fuels: the carbon integrated in the fossil fuel is released back in the atmosphere as carbon dioxide during its combustion. The burning of fossil fuels can also emit methane and nitrous oxide.
- Specific to production process: It is all GHG emissions that could not be explained by the burning of fossil fuels but they are generated by a specific production process (carbonaceous clays, fermentation, outflows of gas fuel transport, waste deterioration, . . .).

The construction of GHG emissions inventory was carried out in accordance with the methodology of the CITEPA (Centre Interprofessionnel Techniques des Etudes de la Pollution Atmosphérique) and the recommendation of intergovernmental panel on climate change (IPCC). The document OMINEA (methods for the construction of national inventories for atmospheric pollutions for France) indicates the GHG emissions coefficients for each fossil fuel. We aggregated then these fossil fuels into four categories: solid fuels (from coal), liquid fuels (from crude oil), gas fuels (from natural gas) and wood. A special feature was made to account GHG emissions from wood. We assumed that $\mathrm{CO_2}$ emissions from the cutting of trees are offset by the carbon sequestration from reforestation. Each trees cut is automatically replanted. So, the carbon footprint is assumed to be zero. However, $\mathrm{CH_4}$ and $\mathrm{N_2O}$ emissions from wood combustion are accounted because it is a result of incomplete combustion. Our GHG emissions inventory was constructed in concordance with the GHG emissions inventory for the Aquitaine region made by the CITEPA for the French Environment and Energy Management Agency (ADEME). GHG emissions can be related to production according to the formula below:

$$E = (e'\widehat{c} + m')P \tag{10}$$

Where
P is the n-vector of production
m is the n-vector of GHG emissions coefficients indicating necessary GHG emissions from specific

production processes (in tCO_2eq) to produce one euro.
c is the n-vector of energy intensity indicating necessary energy consumption (in tonne of oil equivalent or toe) to produce one euro.
e is the n-vector of GHG emissions coefficients indicating GHG emissions resulting of a burning of one toe of fossil fuels.
The apostrophe and the circumflex accent mean respectively the matrix transpose and the diagonal matrix. The letter n indicates the number of sectors. To simplify the notation, we put $k' = (e'\widehat{c} + m')$ where the vector k means total GHG emissions to produce one euro
This formula requires to link economic data with environmental data. However, these different data are expressed in different nomenclatures: NES for economic data, nomenclature of energy consumption (NCE) for energy data and common report format (CRF) for GHG emissions data. A specific nomenclature was created to link these different nomenclatures. This work leads to a nomenclature with 47 sectors that it is able to see in annex. GHG emissions function has been constructed enabling to compute linkage indicators.

3.2 The linkage indicators

The linkage indicators rely on the Leontief model enabling to incorporate the complexity of interindustrial trade for a region. The supply-demand equilibrium of domestic products indicates that the regional production is equal to the sum of the intermediate demand (used for intermediate consumption of sectors) and the final demand of domestic products.
The Leontief model, thanks to the assumption of the stability of the technical coefficients, calculates direct and indirect production (for backward sectors) to satisfy the final demand. Technical coefficients are defined as necessary inputs to produce one euro. For regional studies, it is better to use regional technical coefficients (Miller and Blair, 1985) because it indicated necessary regional inputs to produce one euro of regional product. The production function for a regional economy is written as below:

$$P = A^R.P + Y^d \tag{11}$$

Where
P is the n-vector of production
A^R is the $(n \times n)$ matrix of regional technical coefficients.
Y^d is the n-vector of final demand for regional products.
Equation (11), after rearrangement, can also be written as below:

$$P = (I - A^R)^{-1}.Y^d \tag{12}$$

Where $(I - A^R)^{-1}$ is the inverse matrix of Leontief. It indicates necessary direct and indirect regional production to satisfy one euro of final demand of a regional product. It is possible to extend this model to GHG emissions by integrating (10) into (12):

$$E = k'.(I - A^R)^{-1}.Y^d \tag{13}$$

Where $k'.(I - A^R)^{-1}$ is direct and indirect regional GHG emissions to satisfy one euro of final demand for a regional product.
As we have a large number of sectors (47 sectors), it is difficult to show the results with a so large number of sectors. We use the blocks notion presented by Sanchez and Duarte (2005). The blocks have the interest to show the results in an aggregated way by avoiding the aggregation bias.
Considering B_s a block of sectors of the economy and B_{-S} the remaining sectors. Thanks to

the blocks system and by using the equation (11), the production function can also be written as follow:

$$\begin{pmatrix} P_S \\ P_{-S} \end{pmatrix} = \begin{pmatrix} A^R_{S,S} & A^R_{S,-S} \\ A^R_{-S,S} & A^R_{-S,-S} \end{pmatrix} \begin{pmatrix} P_S \\ P_{-S} \end{pmatrix} + \begin{pmatrix} Y^d_S \\ Y^d_{-S} \end{pmatrix} \tag{14}$$

Equation (14), after rearrangement, can also be written as:

$$\begin{pmatrix} P_S \\ P_{-S} \end{pmatrix} = \begin{pmatrix} \Delta^R_{S,S} & \Delta^R_{S,-S} \\ \Delta^R_{-S,S} & \Delta^R_{-S,-S} \end{pmatrix} \begin{pmatrix} Y^d_S \\ Y^d_{-S} \end{pmatrix} \tag{15}$$

Where $(I - A^R)^{-1} = \begin{pmatrix} \Delta^R_{S,S} & \Delta^R_{S,-S} \\ \Delta^R_{-S,S} & \Delta^R_{-S,-S} \end{pmatrix}$ with $\Delta^R_{S,S} \geq (I - A_{S,S})^{-1}$ and $\Delta^R_{-S,-S} \geq (I - A_{-S,-S})^{-1}$
It is also possible to extend equation (15) to GHG emissions.

$$\begin{pmatrix} E_S \\ E_{-S} \end{pmatrix} = \begin{pmatrix} k_S & 0 \\ 0 & k_{-S} \end{pmatrix} \begin{pmatrix} \Delta^R_{S,S} & \Delta^R_{S,-S} \\ \Delta^R_{-S,S} & \Delta^R_{-S,-S} \end{pmatrix} \begin{pmatrix} Y^d_S \\ Y^d_{-S} \end{pmatrix} \tag{16}$$

Thanks to equations (12) and (16), it is possible to discriminate GHG emissions depending on four effects for each block:

- internal effect: $k'_S(I - A^R_{S,S})^{-1}Y^d_S$
- mixed effect: $k'_S[\Delta^R_{S,S} - (I - A^R_{S,S})^{-1}]Y^d_S$
- net backward effect: $k'_{-S}\Delta^R_{-S,S}.Y^d_S$
- net forward effect: $k'_S\Delta^R_{S,-S}.Y^d_{-S}$

The internal effect indicates emissions produced by the block B_S that are never integrated into the production of goods of the block B_{-S}. The mixed effect is the emissions from the production of goods B_S that are incorporated into the production process as input for the block B_{-S} and come back to B_S to satisfy the final demand. The net backward effect represents the net buying of GHG emissions: it is all GHG emissions from the production of block B_{-S} used as input for the production of B_S in order to satisfy the final demand without coming back to the initial block. The net forward effect represents the net selling GHG emissions: it is all GHG emissions from the production of B_S and used as input for the production of B_{-S} in order to satisfy the final demand without coming back to the initial block.
These different effects will able to calculate both direct and embodied GHG emissions. Direct GHG emissions are composed of all emissions from the production of B_S whatever it satisfies the final demand of B_S than B_{-S}. They are calculating by summing the internal, mixed and net forward effects. They indicate the sector contribution for regional GHG emissions. On contrary, embodied GHG emissions of B_S represents all GHG emissions from direct and indirect production to satisfy the final demand of B_S. They are calculating by summing the internal, mixed and backward effects. The indicated the responsibility of final demand of block B_S for regional GHG emissions.
Block B_S is a net seller of GHG emissions if its direct GHG emissions are higher than their embodied GHG emissions. On contrary, block B_S is a net buyer of GHG emissions if their embodied GHG emissions are higher than their direct GHG emissions.

3.3 Quantitative results

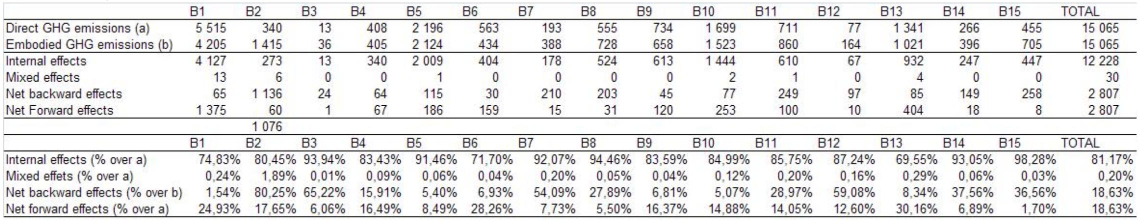
We have first to aggregate sectors into blocks. This aggregation was made in accordance with the classification of NES from INSEE. This classification has the interest to reflect the technology of sectors. We constructed 15 blocks. Code and name of different blocks can be viewed in the table 4 with a relation with our specific nomenclature of 47 sectors.

Table 4: construction of blocks and relation to nomenclature of 47 sectors

Block code	Name of the block	Relation to nomenclature of 47 sectors
B1	Agriculture, Forestry and Fishing	AG1, AG2, AG3
B2	Food-processing industry	AA1-AA5
B3	Textile, leather and clothing	IND10
B4	Wood industry and wood-based products	IND11, IND14
B5	Chemistry, plastic and rubber industries	IND6, IND12, IND13
B6	Metal mineral products and non-metal mineral products industries	IND1, IND2, IND3, IND4, IND5
B7	Manufacture of machines , electric and electronic equipments, equipments for cars	IND 7, IND8, IND9
B8	Construction	IND15
B9	Energy	ENG1-ENG6
B10	Transports	TR1-TR5, S1
B11	Trade	S2
B12	Financial and real estate activities	S3
B13	Services for companies	S4-S8
B14	Services for individuals	S9,S10
B15	Administration and public utilities	S11-S13

The table below shows the results of GHG emissions for the Aquitaine region for 2001 depending on their different effects and indicated in the blocks structure.

Table 5: GHG Emissions for the Aquitaine region: direct and embodied emissions(expressed in $ktCO_2eq$)



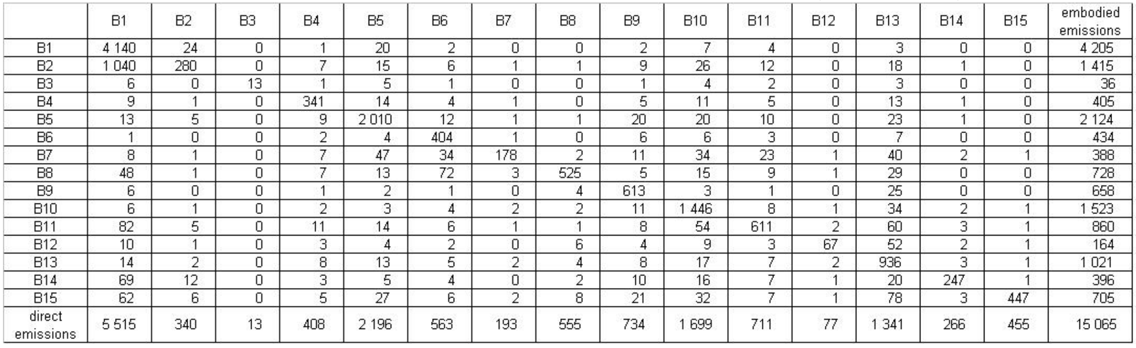
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	TOTAL
Direct GHG emissions (a)	5 515	340	13	408	2 196	563	193	555	734	1 699	711	77	1 341	266	455	15 065
Embodied GHG emissions (b)	4 205	1 415	36	405	2 124	434	388	728	658	1 523	860	164	1 021	396	705	15 065
Internal effects	4 127	273	13	340	2 009	404	178	524	613	1 444	610	67	932	247	447	12 228
Mixed effects	13	6	0	0	1	0	0	0	0	2	1	0	4	0	0	30
Net backward effects	65	1 136	24	64	115	30	210	203	45	77	249	97	85	149	258	2 807
Net Forward effects	1 375	60	1	67	186	159	15	31	120	253	100	10	404	18	8	2 807
		1 076														

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	TOTAL
Internal effects (% over a)	74,83%	80,45%	93,94%	83,43%	91,46%	71,70%	92,07%	94,46%	83,59%	84,99%	85,75%	87,24%	69,55%	93,05%	98,28%	81,17%
Mixed effets (% over a)	0,24%	1,89%	0,01%	0,09%	0,06%	0,04%	0,20%	0,05%	0,04%	0,12%	0,20%	0,16%	0,29%	0,06%	0,03%	0,20%
Net backward effects (% over b)	1,54%	80,25%	65,22%	15,91%	5,40%	6,93%	54,09%	27,89%	6,81%	5,07%	28,97%	59,08%	8,34%	37,56%	36,56%	18,63%
Net forward effects (% over a)	24,93%	17,65%	6,06%	16,49%	8,49%	28,26%	7,73%	5,50%	16,37%	14,88%	14,05%	12,60%	30,16%	6,89%	1,70%	18,63%

The most emitted blocks are B1 (Agriculture, forestry and fishing), B5 (chemistry, plastic and rubber plastic industries), B10 (Transports) and B13 (Services to companies). The contribution to GHG emissions from these different blocks explained by production processes are respectively 37%, 15%, 11% and 9%. So, these four blocks explain 71% of regional GHG emissions. The blocks the most relevant for embodied GHG emissions are the same than direct GHG emissions. It is important to note that the mixed effect is very low. This result is explained by the fact that sectors were aggregated according to technological considerations (Sanchez-Choliz and Duarte, 2005). The most interesting result is the strong internal effect. This result is typical for a regional economy that is a very-open economy. The sectors interdependence within a region is very low

because of strong importation and exportation.
The advantage to distinguish the net backward effect and the net forward effect is to select the most net buyer and net seller blocks of GHG emissions. A net buyer block of GHG emissions is selected by greater net backward effect than net forward effect, implying that direct GHG emissions are lower than integrated GHG emissions. The biggest buyers of GHG emissions are B2, B15 and B7. The net buying [3] of GHG emissions of these respectively blocks are 1,076 $ktCO_2eq$, 250 $ktCO_2eq$ and 195 $ktCO_2eq$. The share of net backward effect is respectively 50%, 37% and 54%. It is interesting to note that blocks B3 and B12 have important net backward effect with respectively rates of 65% and 59%.
The net seller blocks of GHG emissions are B1 and B13. The net selling [4] of GHG emissions for these blocks is respectively 1310 $ktCO_2eq$ and 319 $ktCO_2eq$. The share of net forward effect is respectively to 25% and 30%. It is interesting to note that block B6 has an important forward effect with a rate of 28%.
It is possible to detail information from table 5 by breaking down GHG emissions from net backward and net forward effects between different blocks that you could see on table 6.

Table 6: Breakdown of regional GHG emissions by block (in $ktCO_2eq$)



	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	embodied emissions
B1	4 140	24	0	1	20	2	0	0	2	7	4	0	3	0	0	4 205
B2	1 040	280	0	7	15	6	1	1	9	26	12	0	18	1	0	1 415
B3	6	0	13	1	5	1	0	0	1	4	2	0	3	0	0	36
B4	9	1	0	341	14	4	1	0	5	11	5	0	13	1	0	405
B5	13	5	0	9	2 010	12	1	1	20	20	10	0	23	1	0	2 124
B6	1	0	0	2	4	404	1	0	6	6	3	0	7	0	0	434
B7	8	1	0	7	47	34	178	2	11	34	23	1	40	2	1	388
B8	48	1	0	7	13	72	3	525	5	15	9	1	29	0	0	728
B9	6	0	0	1	2	1	0	4	613	3	1	0	25	0	0	658
B10	6	1	0	2	3	4	2	2	11	1 446	8	1	34	2	1	1 523
B11	82	5	0	11	14	6	1	1	8	54	611	2	60	3	1	860
B12	10	1	0	3	4	2	0	6	4	9	3	67	52	2	1	164
B13	14	2	0	8	13	5	2	4	8	17	7	2	936	3	1	1 021
B14	69	12	0	3	5	4	0	2	10	16	7	1	20	247	1	396
B15	62	6	0	5	27	6	2	8	21	32	7	1	78	3	447	705
direct emissions	5 515	340	13	408	2 196	563	193	555	734	1 699	711	77	1 341	266	455	15 065

The emissions in column indicate the selling of emissions for the final demand of each block. For instance, the block B1 sold 4,140 $ktCO_2eq$ to its final demand, 1,040 $ktCO_2eq$ to B2, 6 $ktCO_2eq$ to B3, and so on. The selling of emissions at the block itself corresponds to mixed and internal effects. So, the sum of GHG emissions in column corresponds to direct emissions. On contrary, the emissions in rows indicate the buying of emissions by a block from different blocks to satisfy its final demand. The final demand of block B1 implied emissions of 4,140 $ktCO_2eq$ to B1, 24 $ktCO_2eq$ to B2, 0 $ktCO_2eq$ to B3, and so on. The buying of emissions from the final demand to the same block corresponds to the sum of mixed and internal effects whereas the sum of emissions of final demand to other blocks corresponds to net backward effect. So, the sum of emissions in row indicates embodied emissions.
The table allows us to select the most important trade of regional GHG emissions between blocks. It is interesting to note that the most important trade of GHG emissions comes from the selling from B1 to B2 (1,040 $ktCO_2eq$), B11 (82 $ktCO_2eq$), B14 (69 $ktCO_2eq$). Moreover, the block B8 buys GHG emissions with B6 (72 $ktCO_2eq$), as well as B15 with B13 (78 $ktCO_2eq$) and B13 with B11 (60 $ktCO_2eq$).
Vertical reading indicates the breakdown of GHG emissions of each block depending on the contri-

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[3] A net buying of GHG emissions is calculated by the difference between net backward effect and net forward effect.

[4] A net selling of GHG emissions is calculated by the difference between net forward effect and net backward effects.

bution of the final demand of each block. This analysis allow us to understand the responsibility of final demand from a block on emissions of an other block though regional interindustrial trade. We find again the same results that we mentioned: As the Aquitaine region is a small and open economy, a large part of block emissions is explained by its final demand (from 70% for the block B13 to 98% for the block B15). We learn that 19% of regional GHG emissions of block B1 are explained by the final demand of block B2, and 13% of emissions of block B6 by the final demand of block B2, and 13% of the emissions of block B6 by the final demand of block B8. Information on the vertical reading can be used to implement some scenarios to reduce emissions of a block to act on the final demand. For instance, we notice that the contribution of the final demand for food-processing products on regional GHG emissions of Agriculture. Horizontal reading indicates the responsibility of the final demand from a block to emissions of all blocks within a region. We find again the influence of the final demand of food-processing industry on emissions of Agriculture because 73% of GHG emissions from the final demand of food-processing industry come from agriculture. Furthermore, 17% and 16% of GHG emissions from respectively final demand of blocks B13 and B3 emanate also from B1. 31% of GHG emissions from the final demand of block B12 emanate of block B13. Thanks to these results, we can list three possible ways to reduce regional GHG emissions:

- to act on the production process for sectors that have important internal and forward effects. A decrease of emissions for these sectors allows respectively a less important contribution to regional emissions and a reduction of embodied emissions for a net buyer sector of GHG emissions. The concerned sectors are essentially agriculture, transports, chemistry, plastic and rubber industries.
- to act on the buying of inputs for the sectors that having a strong net backward effect by substituting inputs less emitting in GHG emissions. The concerned sectors are food-processing industry, public administration, trade, manufacture of machines, electric and electronic equipments and equipment for cars. These sectors though their productive structure have a relatively great impacts on regional GHG emissions.
- to modify the final demand structure in order to substitute the buying of products in favour of products less emitting in GHG emissions. We find again the same sectors than indicated to reduce emissions though a modification of production process.

These three ways can be complementary though it is difficult, in short term, to modify the production process of sectors because of technological costs and the potentiality of existing technology.

4 conclusion

This article shows the relevance at a regional level the input-output analysis for environmental issue that is devoted, here, on GHG emissions. The linkage indicators by using vertical integration allow us to study properly the regional interdependence of sectors for GHG emissions by distinguishing four components. It is a first type of information that can help to implement a regional climate plan.

However, this modelling is based on IOT. Because of poor regional accounting in France, We presented a possible methodology of constructing a regional IOT. This method, with a little use of surveys, enables to construct at a reasonable cost an IOT by incorporating some regional specificities. The recent works on estimation of importation rate of intermediate consumption enables us to have a better estimation of regional technical coefficients, and so, to a better estimation of products trade between sectors within a region. We are however aware about the weakness of the method which is not be very developed. However, construction of a more robust regional IOT must imply a reflection about the development of regional accounting in France that exceeds the aim of this article.

The computation of linkage indicators can be used for the construction of simulations in order to find the least cost strategies to reduce emissions. For instance, it is possible to use linear optimization model in order to quantify the necessary economic restructurings to conciliate economic and environmental targets (Proops et al., 1993). Moveover, new tools were developed leading to more attractive input-output analysis. For instance, the structural decomposition analysis enables to overcome static characteristics of input-output analysis for forecasting studies for short and medium terms (Rose and Casler, 1996).

Annex: nomenclature of IOT for Aquitaine region

code	**Sectors**
AG1	Agriculture
AG2	Forestry
AG3	Fishing
AAI1	Production, processing and preserving of meat and meat products
AAI2	Manufacture of dairy products
AAI3	Manufacture of beverages
AAI4	Manufacture of grain mill products, starches and starch products, prepared animal feeds
AAI5	Manufacture of other food and tobacco products
IND1	Mining of metal ores and uranium
IND2	First processing of iron and steel
IND3	Manufacture of basic precious and non-ferrous metals
IND4	Other mining and quarrying, materials for construction
IND5	Manufacture of glass and glass products
IND6	Chemestry
IND7	smelting and metal works, building of ships and boats, manufacture of equipment, aircraft and spacecraft
IND8	Manufacture of electric and electronic equipment
IND9	Manufacture of v?hicules
IND10	Manufacture of clothing articles, leather products and textiles
IND11	Manufacture of pulp, paper and paper products
IND12	Manufacture of rubber
IND13	Manufacture of plastic products
IND14	other industries
IND15	Construction
ENG1	Mining of coal and lignite; extraction of peat
ENG2	Extraction of crude petroleum and natural gas and manufacture of refined petroleum products
ENG3	Manufacture of coke oven products and processing of nuclear fuel
ENG4	Electricity, steam and hot water supply
ENG5	gas supply
ENG6	Collection, purification and distribution of water
TR1	Transport via railways
TR2	Other passenger land transport
TR3	Freight transport by road or via pipelines
TR4	Water transport
TR5	Air transport
S1	Activities of transport agencies
S2	Trade
S3	Financial and Real estate activities
S4	Post and telecommunications
S5	Consultancy and assistance activities
S6	Renting and other business activities
S7	Sewage and refuse disposal, sanitation and similar activities
S8	Research and development
S9	Hotels and restaurants
S10	Recreational, cultural and sporting activities, personal and domestic services
S11	Education
S12	Health, social work
S13	Administration

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