INPUT-OUTPUT MATERIAL FLOW ANALYSIS APPLIED TO MICROELECTRONIC DEVICES

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Abstract

Since the late 60's many researchers have extended the input–output framework in order to account for the environmental pollution generation and abatement, associated with the industial activity with a choice of the appropriate unit of environmental quantities measurement.

A new approach is to analyze the production process implications on the energy consumption and the several factors associated with that spending process, such as the environment impacts, the pollution and the capital expenditures. The aim of this work is to propose a material flow analysis of two microelectronic devices which have a different daily use in order to quantify the main environmental damages concerning the inputs of the raw materials and of the energetic resources coming from the different steps of the production cycle.

Riassunto

Dagli anni '60 molti ricercatori hanno sviluppato la struttura dell'analisi input–output per rappresentare la generazione degli impatti ambientali e la riduzione di inquinamenti ambientali connessi all'attività industriale, riferiti ad una unità di misura adatta. Un innovativo approccio consiste nell' analizzare le implicazioni del processo di produzione sul consumo di energia e sui differenti fattori connessi con l'impatto inquinante, quali gli effetti dell'ambiente e il consumo di capitale naturale.

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Lo scopo di questo lavoro è di proporre un'analisi di flusso di materiale di due dispositivi microelettronici che hanno un uso quotidiano differente al fine di misurare i danni ambientali principali riguardo agli input delle materie prime e delle risorse energiche che provengono dai punti differenti del ciclo di produzione.

Keywords: input–output materiale flow analysis, microelectronics, environmental impacts.

Introduction

The material flow analysis applied to the production cycles considers the entire productive process highlighting the materials used to obtain specific goods or services included the process scraps, the consumed energy, the emissions and the waste (1).

It underlies also the economic-ecological accounting, because it considers the inputs and outputs without the monetary flows allowing to deeply study well the goods production cycles, and it answers to the needs of obtaining more information about the relationships among the production, the goods and the environment, using tabular plans where *n* activities ("production processes" or "sectors") are represented by their materials inputs and outputs expressed by physical units (2).

The aim of this work is the application of the material flow analysis to the production of microelectronic devices on pure silicon wafers. The inputs quantification is realized studying two microelectronic devices and presenting schematically tables and graphs, which can be easily interpreted and which can help the reader to individuate, clearly and immediately, the materials flows and the relationships among the different steps of the productive cycle.

The materials flow, in particularly the raw materials and the energy ones, has been studied using the data coming directly from a firm which produces the above mentioned devices. With the collected physical data it has been considered the environmental impact of the two devices through the analysis of potential effects as: Acidification, Eutrophication, Ozone reduction, Global warming, Ozon photochemical formation, Toxicity for the human health (3).

The environmental aspects have been consistently evaluated with the assistance of a data processing software, GEMIS 4.5, an analysis model which uses an integrated database including direct and indirect flows, building/dismantlement, energy fluxes (fossil, nuclear, renewable), materials (metals, minerals, food, plastic materials…), transport services (people and goods), and the waste recycling and treatment (4-5).

The result of this study should be used to build a database related to all the microelectronic devices and which should be used as the starting point for future close examinations, applying also Life Cycle Assessment studies conducted on the microelectronics sector (6). This study intends also to characterize a homogeneous approach which allows to standardize the methodology related to the materials flow.

Material Flow Analysis

The material flow analysis gives the opportunity to monitor the economic activities related to the production and the consumption in order to allow the redesign of the social-economic system looking at the substainable development; it allows also to determine the relationship between the production of the goods and the environmental impacts associated with the different steps of the production. From a micro-economic point of view this analysis regards an interrelated productive processes chain which interests just one of it and whose aim is to record the material flows which bind together the different steps of the productive cycle.

The perspective of a productive chain reminds the concept of the physical life cycle, which inspires the Life Cycle Analysis approach and whose calculus structure is very similar, but it better underlines the causal relationships between the production results and the environmental impacts associated to it in order to better plan the energetic resources and materials needs and the pollutants abatement methodologies (7).

The material flow analysis allows a detailed analysis due to some simulations but its limit is that the same simulations are often connected to specific scenaries which cannot be adapted to the studied ones.

This methodological approach allows to evaluate quantitatively the current environmental problems coming from a productive process, to go back up the pollutants used for the life cycle of a product or of a process and which are responsible for the main pollution events; moreover, using a virtual scenary, it is possible to verify the feasible improvements using innovative techonologies. This analysis wants also to individualize and point out the possibilities to reduce the environmental impacts connected to the life cycle of the products; to support internal decisions regarding interventions on the processes, products and activities; to identify the strategic lines to develop new products or services following an eco-compatible approach and allowing a continuous improving process.

Productive Steps of the Study

The *microeletronics* sector has recorded during the last 50 years an incredibile develop higher than other product sector or technology and, constantly and endlessly, improving the various technical parameters (linear dimensions treated on a *chip*, number of devices per *chip*), the unit price and the performances (*chip* information storage capabilities) (8).

The Integrated Circuit, identified also as microchip or simply chip, is a miniaturized electronic circuit and it is presented as a single electronic component where, instead, all the components (resistors, condensers, diodes, transistors, field-effect transistor or FET) have been made out of a only plate of semiconductor material (es. silicon or gallium arsenide) during the same working process; for this reason they are also called *monolithics* (9).

The step studied in this work refers to the productive cycle concerning the wafer devices manufacturing and include the following steps: Diffusion, Implanting, Masking, Connectors, Lapping, which are the productive steps more used into the microelectronic Italian firms.

The exact quantity of material and of energy necessary for their realization have been provided by a sector firm and represent, on average, the values closer to all the same productive cycles.

The other steps which refer to the silicon slice production on which the devices are built, the separation of them and their packaging are generally realized by firms whose offices are out from the national country, so it is difficult to get data about the first steps of their productive cycle. For this reason, the study begins with the physical quantification of the inputs necessary for the devices production starting from the evaluation of the impacts coming from this step of the production. This is the main step and it is the more complex of the entire product life cycle, because it has to be developed using the primary data.

The result of the study, as it has been pointed out before, should be useful to build a “database” which will allow to quantify the material consumption during each step of the production.

Here below it has been listed the events which constitute the productive process and the related raw materials used and collected on the basis of their typology:

Oven: SiH_2Cl_2, NH_3, SiH_4, $POCl_3$, $C_2H_2Cl_2$, H_2, O_2, N_2;

Implanting and epitaxial reactor: BF_3, $Sb(CH_3)_3$, AsH_3, PH_3, $SiHCl_3$, H_2, N_2;

Deposition and lapping: DIW, B_2H_6, PH_3, SiH_4, O_2, N_2;

Washing: DIW, H_2SO_4, H_2O_2, NH_4OH, HCl, HF, NH_4F, H_3PO_4, N_2;

Covering and exposure: OiR_906_12j[*1], AZ_4533[*1], OiR_906_17HD[*1], OPD4280[*1], HPRD429[*1], RER500[*1], $C_6H_{12}O_2$, C_5H_9NO, PIX[*1], SOG[*1], C_3H_8O;

Plasma: NF_3, CHF_3, CF_4, C_2F_6, SF_6, Cl_2, BCl_3, HBr, N_2O, O_3, $Si(OCH_3)_4$, SiH_4, NH_3, He, Ar, H_2, O_2, N_2;

Second washing: DIW, CH_3COOH, NH_4F, FRECKLE[*1], FPN[*1], SpinetchD[*1], EKC[*1], C_3H_8O, N_2;

Evaporation and sputtering: Al, Si, Cu, Cr, Ni, Ti, Ar, N_2.

In Table 1 it has been presented the general environmental aspects involved in each of the studied productive step and which will be analyzed later, more in detail.

[1] The abbreviations represent the liquid commercial chemical products whose composition, written in the relative security specifications, is not indicated here because it is an industrial secret. This analysis will omit the quantification of these mistures.

TABLE 1

ENVIRONMENTAL ASPECTS DURING THE DIFFERENT STEPS OF THE WORKING PROCESS

STEPS	ENVIRONMENATL ASPECTS
Epitaxial Increase[2]	Use of Electric Power and of liquid and gaseous products; Atmospheric Emissions containing hydrochloric acid (with the removal by means of *scrubbers*)
Diffusion[3]	Use of Electric Power, of liquid and gaseous products and of extra-pure water; Emissions into the atmosphere
Photolitothography[4]	Use of Electric Power, of chemical products, of extra-pure water; Emissions into the atmosphere; Waste production
Chemical attacks,clearing and extra washing[5]	Use of extra-pure water and of chemical products; Emissions into the atmosphere; Discharge of industrial wastewater containing chemical substances (which will be treated into the depuration plants); Waste production
Metalizzation[6]	Use of Electric Power, of chemical products, of extra-pure water
Ion Implantation[7]	Use of Electric Power
Electric Control - EWS[8]	Use of Electric Power
White Chambers[9]	Use of Electric Power
Assembling Pilot line (*Back –End*)	Use of extra-pure water (during the ruling phase); Use of gas (hydrogen with nitrogen); Use of Electric Power; Waste (thermosetting resin, copper, particulates)

Source: Personal elaboration.

[2] High temperature vapour-phase chemical process for the deposition of monocrystalline silicon layers appropriately doped with external substances.
[3] High temperature thermal process to spread the atoms of other elements into the silicon in order to obtain a different conductivity.
[4] Creation of non protected silicon areas where it can be implanted other types of atoms or metallic connections between the adjacent transistor.
[5] Materials remotion in specific device areas.
[6] Deposition on the silicon surface of metal layers to connect the device transistors.
[7] Borio ions and phosphorus adding in the silicion.
[8] Automated test of the features, quality and devices reliability.
[9] Rooms where each actions is done in a totally absence of particles.

Physical Quantification of the Materials

The analysis of the inputs physical quantification interests, in particularly, the productive process of two microelectronic devices: the first device called “Device 1” (D1) belongs to the automotive category, the other one called “Device 2” (D2) is a switch it means an electronic device able to stop an electric circuit used to realize more complex applications.

These two products have been chosen because they present a different number of masks (D2 has 6 masks while D1 has 14 masks[10]) and because the size of the wafers on which they are realized, is different (D2 is “8” while D1 is 6”).

It has to be underlined that the data referred to the raw materials consumption have been obtained by the analysis of the formulas and so they can be considered as “certain” data if the wafer is considered as a referring unit, while they are considered “quite certain” data if they refer to a single chip. Considering that all the starting data refer to the wafer and/or to the lots, it has be made a proportion in relation to the number of the devices per slice and to the number of maskings.

The productive process starts from the virgin wafer. As it has already said for the analyzed products, the slices have a different size: the D2 is a slice of 8” and its weight is 53.2356 g while the D1 is a slice of 6” and its weight is 20.4748 g.

In Table 2 it has been presentated the quantities used for the production of each component.

[10] The masking is a step of the wafers manufacturing process during which, using sophisticated photographic tecniques, very small geometries are reproduced on the surface of the slices and they will constitute, step by step, the visible configuration of the integrated circuit.

TABLE 2

MATERIAL QUANTIFICATION PER CHIP

Chemical element in gram	D1	D2
N_2 (Nitrogen)	$29{,}752.84952\times10^{-6}$	$63{,}193.98231\times10^{-6}$
O_2 (molecular oxygen)	165.345303×10^{-6}	$72{,}220.1324\times10^{-6}$
$Si\ H_4$ (silane)	$231{,}000\times10^{-6}$	$288{,}549.1\times10^{-6}$
CF_4 (tetrafluoromethane)	$1{,}971.0048\times10^{-6}$	$1{,}178.4588\times10^{-6}$
HF (hydrofluoridric acid)	4.78016×10^{-6}	$593{,}328.921\times10^{-6}$
H_3PO_4 (phosphoric acid)	$32{,}054.425\times10^{-6}$	$28{,}783{,}661.6\times10^{-6}$
H_2SO_4 (sulphuric acid)	$96{,}964.32\times10^{-6}$	$1{,}380{,}167.44\times10^{-6}$
HNO_3 (niric acid)	27.23992×10^{-6}	19.02888×10^{-6}
NH_4OH (ammonium hydroxide)	71.6294×10^{-6}	288.85422×10^{-6}
H_2O_2 (hydrogen peroxide)	$23{,}604.042\times10^{-6}$	$835{,}361.296\times10^{-6}$
IPA (isopropyl alcohol)	$6{,}047.36\times10^{-6}$	$7{,}389{,}307.2\times10^{-6}$
B (boron)	$849{,}644.64\times10^{-6}$	$16{,}014{,}144.64\times10^{-6}$
As (Arsenic)	$1{,}552{,}235.4\times10^{-6}$	$19{,}165{,}509\times10^{-6}$
H_2 (hydrogen)	549.5×10^{-6}	//
SiH_2Cl_2 (dichlorosilane)	13×10^{-6}	//
NH_3 (ammonia)	70.932×10^{-6}	//
PH_3 (phoshine)	0.104×10^{-6}	//
TEOS (tetraethyl ortho silicate)	$1{,}739.1\times10^{-6}$	//
Cl_2 (chlorine)	368.325×10^{-6}	//
HBr (hydrobromic acid)	$212{,}577.2\times10^{-6}$	//
He/O_2 (gaseous mixture)	$252{,}214.2\times10^{-6}$	//
Ar (argon)	508.446×10^{-6}	//
CHF_3 (trifluoromethane)	24.498×10^{-6}	//
CO (carbon monoxide)	58.815×10^{-6}	//
BCl_3 (boron thricloride)	$51{,}540.3\times10^{-6}$	//
FPN (fluorophenol)	$129{,}733.52\times10^{-6}$	//
N_2O (nitrogen protoxide)	//	$7{,}909{,}006.8\times10^{-6}$
N_2H_2 (diazine)	//	$1{,}979{,}136.915\times10^{-6}$
Sb (antimony)	//	$4{,}802{,}153.22\times10^{-6}$
Ti (titanium)- (Å)	4.7867×10^{-23} g	4.7867×10^{-23} g
Ni (nickel vanadium)- (Å)	3.7563776×10^{-22} g	3.7563776×10^{-22} g
Au gold - (Å)	7.878662×10^{-23} g	7.878662×10^{-23} g
EKC (liquid mixture) (l per chip)	4.373×10^{-6}	$7{,}022.9\times10^{-6}$
DIW (deionized water)	416.493×10^{-6}	$1{,}221{,}374.046\times10^{-6}$
BOE (mixture) (l per chip)	0.624×10^{-6}	$9{,}160.305\times10^{-6}$

Source: Personal Elaboration of the company data.

The mark // doesn't indicate that the raw material hasn't be used, but it means that its use is less than 0.00000001 g, and this study doesn't consider it particularly interesting, except for the metals Ti, Ni and Au; these components, infact, are fired as atoms directly on the slice and they remain sticked to the surface of the chamber where the operation occurs and then they are sucked out to be dumped.

Quantification of the Energetic Resources

The energetic resources used by the analyzed firm are the electric power and the natural gas. The data concerning the energy consumption has been obtained examining the environmental declaration drawn up by the firm in 2009 and referred to an equivalent Standard Wafer Out (Std WO eq), it means a silicon wafer with a diameter of 8" which is equivalent to 200 mm and with a number of maskings equal to 20 (Table 3).

The studied devices which do not fall into this standard have been converted using the coefficients Sr/Ss (effective surface/standard surface) and Mr/Ms (number of real maskings/number of standard maskings).

The electric power is used both to feed the production equipment and to feed the technological plants used to produce and distribute the services requested by the production.

The natural gas is involved into the production of the hot heat-transfer, which are used for the conditioning of the cleanrooms where the imposed thermohygrometer conditions (temperature and humidity), have to be constantly maintained. The high pressure gas which arrived to the firm is reduced till the pressure used inside the plant and it feeds the thermal-electric power plants for the production of 60 °C hot water, over-heated water till 150 °C and 4 bar vapour (Table 4 and 5).

TABLE 3

COMPARISON BETWEEN THE PRODUCT CONSUMPTION AND THE STANDARD WAFER OUT

Evaluations per wafer	Std/Wo eq	D2	D1
Electric Power (Milions kWh)	239.85	147.48	369.375
Methan gas (thousands Sm^3)	7.6	2.28	5.7

Standard Cubic Meter Sm^3: Volume Unit of measure used for the gases, in "standard" conditions: it means considering the atmospheric pressure and the 15 °C temperature.
Source: personal elaboration.

TABLE 4

CONSUMPTION EVALUATION OF METHAN GAS AND ELECTRICAL ENERGY PER CHIP

Methan gas	**D2**	**D1**
Sm^3 in chip	474.802×10^{-6}	$8,702.29 \times 10^{-6}$
Electric Power	**F3L2D**	**VB325SP**
Kwh in chip	$30,712.203 \times 10^{-6}$	$563,931.279 \times 10^{-6}$

Source: personal elaboration.

The used water is at first transfered to the treatment plants for the production of ultrapure water necessary for the wafers processing. The ultra pure water production involves also electric power consumption and use of chemical substances, active carbons and ion-exchange resins.

TABLE 5

QUANTIFICATION OF THE RAW AND ULTRAPURE WATER CONSUMPTION PER CHIP

Raw Water	**D2**	**D1**
thousands m^3 per chip	378.592×10^{-6}	$6,938.931 \times 10^{-6}$
Pure Water	**D2**	**D1**
thousands m^3 per chip	124.947×10^{-6}	$2,290.076 \times 10^{-6}$

Source: personal elaboration.

Impacts Analysis

The results of the inventory analysis have been assigned to impact categories which, according to the Eco-indicators, have been detected on the strength of the effects that they cause or could cause on the environment.

Following this method, it has been given a “weight” to the different substances. This weight is an adimesional value assigned in relation to the effects that the substances have on the environment.

All the calculations done by the processors which adopt the Eco-indicators method allow the creation of a number (eco-indicator) which represents a specific damage caused by the emission of a substance emanated during any of the analyzed process.

In this case it has not been used the eco-indicators, but the eco-indicators method in order to assign the emissions to the relative damage category. For this reason, the total result has been espressed in quantity and not in "indicator number".

The Eco-indicators method is *damage-oriented*, it means that it divides the impacts into three damage macro-categories which describe different impact categories. The damage categories examined for the eco indicators analysis are three:
- Human health;
- Ecosystem quality;
- Resources consumption.

Each of the three categories is divided into other more impact categories which, in turn, have been configured by the aggregation of all the substances (consumed and emitted during the esamined processes) which, as it is known or supposed, are considered as the responsible of the impact and of the connected damage (10). Through the use of models, it is possible to connect the inventory substances to the damage categories and to the corrisponding impact categories (Table 6).

TABLE 6

IMPACTS CATEGORIES

DAMAGE CATEGORY	IMPACT CATEGORY
Human health	Carcinogenic substances
	Respiratory diseases caused by organic substances
	Respiratory diseases caused by inhorganic substances
	Climatic Changes
	Ionizing radiations
	Ozone depletion
Ecosystem Qualities	Ecotoxicity
	Acidification/Eutrophication
	Use of the soil
Resources Consumption	Minerals
	Fossil fuels

Source: Bollettino di informazione ambientale, Guida all'analisi del ciclo di vita, ANIE Servizio Centrale Ambiente, Milano 2002.

If it is assigned to each impact category the parameters determined by the inventory analysis, the data classification is determined (Table 7).

TABLE 7

SCHEME OF THE CLASSIFICATION PHASE ACCORDING TO THE ENVIRONMENTAL EFFECTS

Gaseous Emissions	Green house effects	Human toxicity	Photochemical ozone formation	Acidification	Ozone reduction
CO_2	X				
SO_2				X	
CH_4	X		X		
NO_2		X	X	X	
Propane, butane, Heptane			X		
Benzene		X	X		
As, Cr, Cu, Se, Cd, Hg, Zn, Pb, V, Co, Ni		X			
HF		X			
NH_3		X		X	
HCl		X			
N_2O	X				X
CO			X		

Source: Bollettino di informazione ambientale, Guida all'analisi del ciclo di vita, ANIE Servizio Centrale Ambiente, Milano 2002.

It has to be pointed out that a parameter of the inventory analysis can be assigned to different impact categories. The defined impact categories are different according to the scale with which they show their effect towards the environment. In particularly it has been defined:
- Global impacts. which concern the entire planet;
- Regional impacts, which regard a wide area (some thousand of km^2) around the place where the impact occurs;
- Local impacts which regard just the area around the point of impact.

Each impact (input and output of the life cycle phases), quantified during the inventory step, is "classified" according to the environmental problems which it can pontentially cause. The effects of these impacts have been reported in Table 8 according to their Scale of influence.

TABLE 8

EFFECT SCALE

SCALE	EFFECT	ACRONYM
GLOBAL	GLOBAL WARMING	GWP
	OZONE DEPLETION IN TO THE ATMOSPHERE	ODP
	NOT RENEWABLE RESOURCES CONSUMPTION	
REGIONAL	ACIDIFICATION	AP
	EUTROPHICATION	NP
	OZONE PHOTOCHEMICAL FORMATION INTO THE TROPOSPHERE	POCP
LOCAL	TOXIC EFFECTS TOSSICI ON HUMAN HEALTH	HTP
	ECO- TOXICITY OF THE AREA	ETP

Source: Bollettino di informazione ambientale, Guida all'analisi del ciclo di vita, ANIE Servizio Centrale Ambiente, Milano 2002.

Global Results and Attribution of the Emissions to the Impacts

The Gemis 4.5 software, used for the analysis of the emissions of the D1 and D2 products with the help of its integrated database allows to study the direct and the indirect flows, the building/dismantlement, the energy flows (fossil, nuclear, renewable), the materials (metals, minerals, food, plastic materials…), and the transport (people and goods) and also the recycling and the waste treatment, and to quantify the emissions in the environment for the environmental indicators which take into account.

In particularly: the emissions into the atmosphere (SO_2, NO_x, particulated, HCl, HF, H_2S, NH_3, CO, COVNM), the green-house effect gas (CO_2, CH_4, N_2O, altri gas), the liquid effluent (AOX, BOD, COD, N, P, inorganic salts), the solid waste (ashes, overload, process waste), the soil use and the use of the resources (primary energy and the requests of the primary material).

According to the Gemis 4.5 software analysis the global results concerning the emissions in the air and the greenhouse effect caused by the D1 and the D2 device are reported in Table 9.

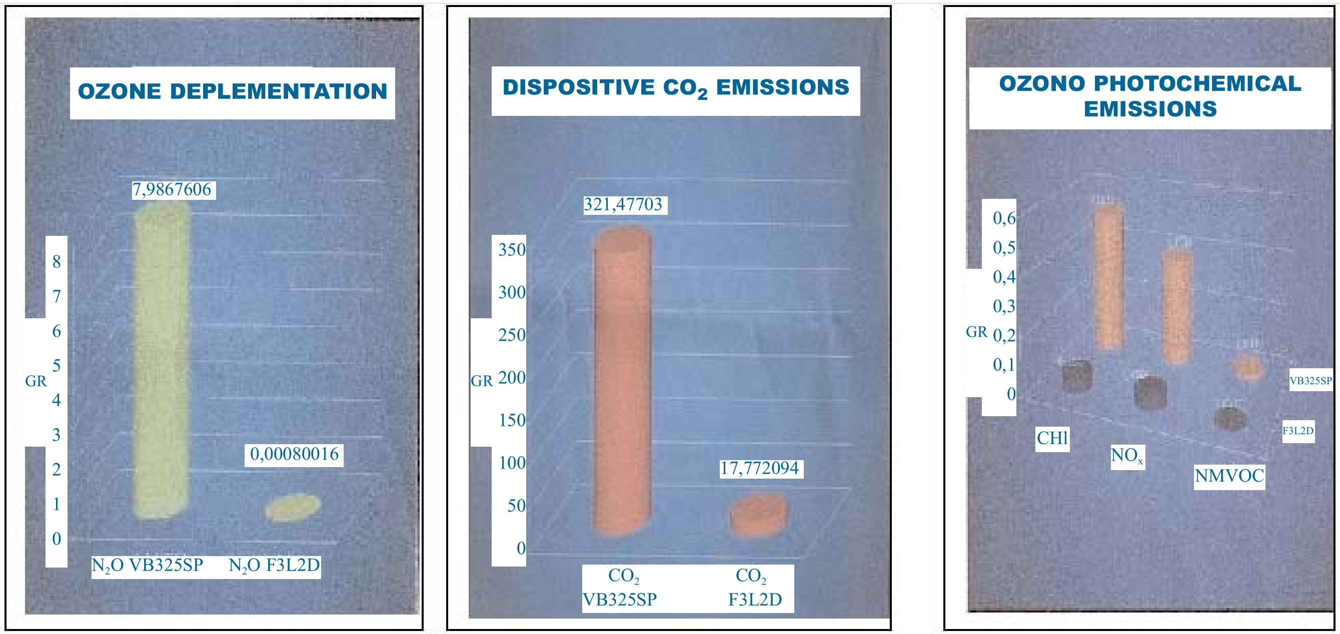
TABLE 9

D1 AND D2 GAS EMISSIONS IN THE AIR AND D1 AND D2 GREEN HOUSE GAS EMISSIONS

Substance	D1 g	D2 g	Substance	D1 g	D2 g
SO_2 equivalent	1.4573793	51.123×10^{-3}	**CO_2 equivalent**	2.81587×10^{-3}	27.068488
TOPP equivalent	504.08×10^{-3}	63.587×10^{-3}	**CO_2**	321.47703	17.772094
SO_2	202.30×10^{-3}	11.402×10^{-3}	**CH_4**	513.36×10^{-3}	52.320×10^{-3}
NO_x	377.19×10^{-3}	49.802×10^{-3}	**N_2O**	7.9867606	800.16×10^{-6}
HCl	12.285×10^{-3}	3.5679×10^{-3}	**Perfluoromethane**	1.1858×10^{-3}	1.1789×10^{-3}
HF	593.96×10^{-3}	39.151×10^{-6}	**Perfluoroethane**	924.89×10^{-9}	50.374×10^{-9}
Particulates	30.333×10^{-3}	1.6702×10^{-3}	**HFC-23**	//	24.498×10^{-6}
CO	138.91×10^{-3}	7.7616×10^{-6}			
NMVOC	21.447×10^{-3}	1.2421×10^{-3}			
H_2S	1.3839×10^{-3}	97.166×10^{-6}			
NH_3	14.942×10^{-3}	886.43×10^{-6}			
As (air)	19.170×10^{-3}	1.5525×10^{-3}			
Cd (air)	1.2936×10^{-6}	72.235×10^{-9}			
Cr (air)	4.0014×10^{-6}	223.41×10^{-9}			
Hg (air)	4.2839×10^{-6}	241.91×10^{-9}			
Ni (air)	15.593×10^{-6}	873.93×10^{-9}			
Pb (air)	13.549×10^{-6}	771.44×10^{-9}			
PCDD/F (air)	8.615×10^{-12}	487.2×10^{-15}			

Source: personal elaboration.

In order to quantify the greenhouse gas emissions and the gases responsible for the ozone depletion produced by both of the two devices, the data of the table have been conveniently elaborated and illustrated in Figures 1-3.



Source: personal elaboration.

Fig. 1-3 – Quantification Of The Greenhouse Emissions And Of The Greenhouse Gas And Of The Gases Responsabile For The Ozone Depletion.

From the data in the table and from the Figures 1-3 the more relevant greenhouse gas is the CO_2, a gas which is more present in the D1 device than in D2 device; the GWPs greenhouse gases are calculated for each greenhouse gas considering their radiation absorption capacity and the time of permanence into the atmosphere; in particularly the GWP of each examined gas is calculated considering the relation between the contribution that the instantaneous release of 1 kg of that substance and that given by the emission of 1kg of CO_2 give to the absorption of the hot radiation, considering that the contribution of their permanence into the atmosphere has been calculated for a period of time of T years (generally 100 years).

It has to be noticed that the methane (CH_4) which is the second important greenhouse gas, is ranked just at the third place in order of magnitude. The second for quantity is the nitrogen protoxide; a clearer graphic vision of the nitrogen protoxide is visible in the graph which measures the nitrogen reduction.

In Table 10 it has been listed the global results of the emissions into the water for D1 and D2 devices according to the Gemis 4.5 software analysis.

TABLE 10

D1 AND D2 LIQUID EFFLUENTS

Substance	D1 g	D2 g
P	151.38×10^{-9}	10.066×10^{-9}
N	9.0052×10^{-6}	597.34×10^{-9}
AOX	18.935×10^{-9}	1.1844×10^{-9}
COD	24.955×10^{-3}	1.4263×10^{-3}
BOD5	706.13×10^{-6}	40.361×10^{-6}
Inorg. Salt	538.97×10^{-3}	30.085×10^{-3}
As (liquid)	13.47×10^{-12}	733.8×10^{-15}
Cd (liquid)	32.89×10^{-12}	1.792×10^{-12}
Cr (liquid)	32.54×10^{-12}	1.773×10^{-12}
Hg (liquid)	16.45×10^{-12}	896.1×10^{-15}
Pb (liquid)	214.5×10^{-12}	11.69×10^{-12}

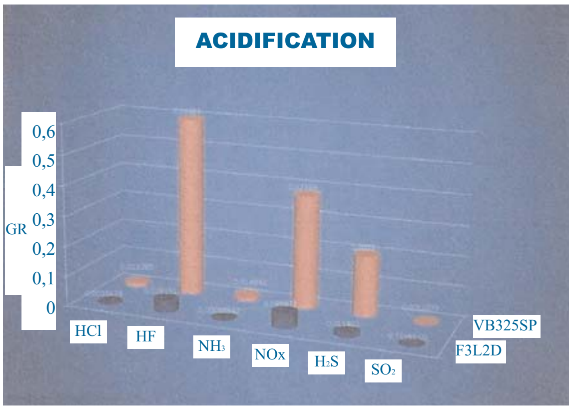
Source: personal elaboration.

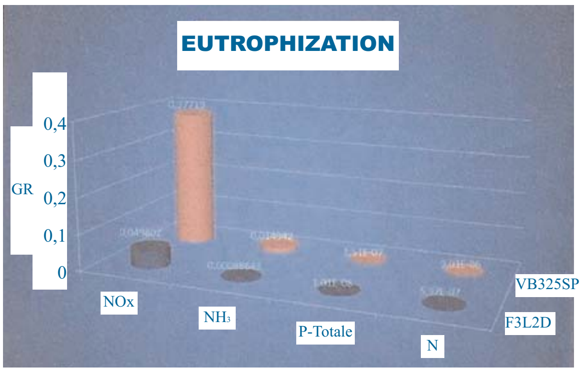
In order to quantify the acidification it has been aggregated the values of the emissions potentially acid of O_2, NOx, and also of HF, HCl, NH_3, H_2S. The substances which contribute more on the acidification are: the hydrofluoric acid (HF), the nitrose oxides (NOx) and the sulphur dioxide (SO_2) even if they act in a different way. In D1 device the HF is higher than in D2 device where, on the contrary, the NOx are higher.

Also for this impact category the D1 device has more emissions.

As far as the toxicity of a substance on the organism is concerned, it depends both on the quantity that it takes and the ways of exposure. Generally it has been taken the data concerning the Arsenico (As) emissions, the Nickel (Ni) and the Sulphurous Anhydride or Sulphur (SO_2) dioxide.

The Figures 4 and 5 show as the Sulphur dioxide (SO_2) is higher than the Nikhel and the Arsenic.





Source: personal elaboration.

Fig. 4-5 – Acidification And Eutrophication Trend For The Two Devices.

Interpretation of the Results

The comparison between the two devices shows that the D1 device bears on each of the impact categories more than D2 one. It can be explained considering that the two studied products are realized using different procedures.

The first difference is the number of maskings: D1 has 14 maskings which are twice over the 6 of D2 and it means more substances and, as a consequence, more emissions; D1 is realized on a 6" inches slice while D2 on 8" inches slice; in the first slice it has been realized 655 devices of the D1 type, while in the second one it has been realized 4802 devices of the D2 type: in proportion an high number of devices on a 8" slice and consequently a substances saving because the devices get in contact with them not singly, but for each slice. For the D1 realization it has been used substances like N_2O and N_2H_2 which put a strain on the greenhouse effect. The same substance are not used for the D2 device and in any case, if used, their quantity is really insignificant.

The differences noticed between the two devices do not respect the proportion relating to the maskings and the events (respectively twice over and triple over), even if the D1 emissions are constantly higher than the D2 device.

In order to reduce the environmental impacts connected with the production of the studied devices, it's necessary to reduce the pollutants, optimizing the processes or using alternative compounds which have a lower potential effect and, if necessary, which can increase the efficiency of the treatment plants and of the waste management system.

The phosphoric acid, for example, could be more diluted or it could be installed plants which use a less quantity of it while the acids which contribute to the acidification process could be substituted with other ones which have a lower acidification potential.

According to the data obtained by the software, the D1 device impact is higher than the D2 one in all the impact categories: it means that the first one emits more substances than the second one and it has a higher impact during the acidification process, the eutrophication process, in the global warming, in the toxicity for the human beings and for the ozone photochemical formation. The substances into the devices which are more responsible for the acidification process are: the hydrofluoric acid (HF), the nitrogen oxides (NO_x) and the sulphur dioxide (SO_2) which are divided in the D1 device as follows 0.59396 g, 0.37719 g, 0.2023g and which are higher than in the D2 which emits 0.039151 g, 0.049802 g, 0.011402 g. The presence of CH_4 into the D1 device (0.51336 g) is ten times than the D2 (0.05232 g), a presence which greatly contributes to the greenhouse effect and to the ozone photochemical formation.

The use of ammonia is quite 17 times in D1 (0.014942 g) than in D2 (0.00088643 g), a great use during the eutrophication process: this is surely due to the different productive processes of the two devices.

Conclusive Remarks

From this analysis brings out some limits, in particularly the raw materials consumption data have been obtained by the receipts analysis and so they can be considered "certain" data if they refer to the wafer as a reference unit but they are "quite certain" if they refer to the sole chip.

First of all, in fact, it has been assigned the raw materials in proportion to the single device referring to the coefficients connected to the masking numbers and to the slice surface. The earlier and later outputs have been considered as the only data, because the specific analysis on each device about the chemical-physical reactions which happen during the various steps are missing.

Just a few of the studied effects have been taken into account: a deeper study, in fact, could include a study regarding also the noise pollution. According to the data obtained by the software on the two devices, the D1 has a deep impact than the D2, into all the impact categories, because its productive process is more complex and the quantity of the used raw material is different. A LCA study on the single devices could point out better the step which produces more emissions, even with the help of counters put into the machines to count the right consumptions and to take measures to reduce and/or to improve the used technologies.

In short, the right application of the material flows analysis applied to the single productice processes could guarantee an efficient improvement and an effective management of the quantities improved into the economic activities, because the compilation of a database concerning each single step of the productive process lies at the bottom of a source of information useful for the development of several instruments for the environmental assessment.

Moreover the material flow analysis is able to represent the environmental pressures during each step of the life cycle, from the extraction to the production, distribution and consumption, giving also some information about the substainability indexes which answer to the need of monitoring and evaluating the environmental performaces of each productive process.

The lack of a method standardization and of a methodology which could make the application homogeneous spurs the experts to propose operational approaches in order to create a "standardized methodological guideline" which allows the comparison of the method and the integration of the results.

The study of the material flow could give an active contribution both from a methodological and from a method standardization point of view. Its application will be extended to other productive processes in order to show how versatile is its applicability.

The use of this method will allow, also, to monitor always the production activities and the consumptions of the society and to fix up clear, right, true and complete information about the relationship between the production and the environment which is addressed to the experts and the politicians, with the intention of looking at the industrial ecology.

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