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Life Cycle Assessment of Peach Nectar: a comparative analysis between conventional and bioenergy-from-waste integrated food chains

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1 Introduction

1.1 Subject and objectives

Modern food systems are characterized by one of the highest energy intensity among human activities as well as by the production of large amounts of waste, residuals and food losses. This systemic inefficiency presents major environmental consequences, in terms of GHG emissions, waste disposal, and natural resource depletion.

The research hypothesis is that residual biomass materials (constituted by waste, by-products, unsold products, food losses) could contribute to the energetic needs of food systems, if properly recovered as an integrated renewable energy source (RES), leading to a sensitive reduction of the environmental impacts of food systems, primarily in terms of fossil fuel consumption and GHG emissions.

In order to assess these potential effects, a comparative life cycle assessment (LCA) has been conducted to compare the environmental impacts of two different food systems: a fossil fuel-based system and an integrated system with the use of residual as RES for self-consumption. The food product under analysis has been the peach nectar, from cultivation to end-of-life. The aim of this comparative LCA is twofold. On one hand, it allows an evaluation of the energy inefficiencies related to agro-food waste generation and management. On the other hand, it illustrates how the integration of bioenergy from waste into food systems could effectively contribute to reduce this inefficiency.

Data about energy inputs and waste generated has been collected mainly through literature review and databases. Energy balance, GHG emissions (Global Warming Potential) and waste generation have been analyzed in order to identify the relative requirements and contribution of the different segments of the production chains. An evaluation of the energy “loss” through the different categories of waste (from field residuals to edible food waste) allowed to provide details about the consequences associated with its management and/or disposal.

Results should provide an insight of the environmental impacts and costs associated with inefficiencies within food systems. The comparison between the two different systems provides a measure of the potential reuse of wasted biomass and the amount of energy that can be recovered through integrated bioenergy. This measure could also represent a first step for the formulation of specific policies on the integration of bioenergies for self-consumption.

This research aims at analysing the integration of food production with the self-generation of renewable energy from the numerous waste, discards and by-products of the food chain, from the environmental point of view. In fact, the integration of bioenergy into food production could effectively facilitate the transition of agriculture and livestock sector towards a sustainable, low-carbon economy, reducing toward zero the use of fossil fuel, compensating for other kind of emissions, and solving the problematic disposal of some waste (like manure, used vegetable oil, unsold products,...). Furthermore, this transition could lead to other positive impacts in terms of rural development: the multiple externalities range from the reduction of dependence on increasingly expensive fossil energy to the diversification of income from agriculture, from the creation of new jobs to the development of new skills, from the recovery of remote areas to the supply of modern services (e.g.: heating from renewable sources).

2 State of the art

2.1 The food-energy nexus: between competition andintegration

In the recent years, the energetic dependence of world economy on fossil fuels has been increasingly acknowledged as one of the crucial issues, that could simultaneously endanger our future way of life, well-being and survival. In this scenario, there's a greater awareness of food production not only as a basis of human life, but also as one of the most energy intensive economic activities. From fields to retailers, from transport to garbage, every step of food production and consumption gives rise to the inefficient use of about the 15% of the total energy consumption. The unmatched yields, guaranteed by the so-called "Green Revolution", led to the satisfaction of basic food needs in all the developed countries, as well as to relevant environmental and economic consequences (Cuellar & Webber 2010).

According to recent IPCC estimates, agriculture accounts for about 13% of global emissions, but this figure detects only in part factors as energy consumption, impact of transport, change of land use, agro-food industry (IPCC, 2007). The production of animal derived food implies a share of 18% of global greenhouse gas (GHG) emissions, equivalent to industry and higher than transports (Steinfeld et al. 2006). Our food choices happen to be as crucial as private mobility ones (Eshel & Martin 2006).

2.2 The agro-food wastes and bioenergy

Despite the massive amount of resources depleted and the resulting energetic burden, the contemporary intensive food production and consumption entail the intensive creation of large quantities of residues, waste and by-products. Around 5% of 520 million tons of maize annually cultivated is wasted, mostly because of logistical reasons, not taking into account the consumption waste (Kim & Dale 2004). Only in 1994, the quantity of manure deriving from livestock sector was 3 billion tons (Wirsenius 2000), while the USDA reported a 27% of available food wasted in 1995, excluding food wasted on farm, in fisheries, and during processing. The list of examples could include, among others, the remains of pruning, production by-products, unsold goods, organic and potentially dangerous waste as used vegetable oil (FAO 2008). This unexploited biomass, that represents a systemic inefficiency and the depletion of limited resources, could be used as source of heat and power generation.

2.3 The economics and politics of food-energy nexus

Since the turn of the millennium, bioenergy production has marked the largest percentage growth among all renewable energies, with bioethanol and biodiesel respectively increasing three and ten times since 2000 (REN21 2006; FAO 2008). This renewed interest originates from bioenergy potential in terms of GHG emission reduction, rural income diversification, decreased oil dependence, and electricity generation. Nevertheless, this development generated an intense debate about the alleged potentialities ascribed to bioenergy. To a certain extent, biofuels growth gave rise to a competition with food production, the diversion of natural resources, and the land-use change, contributing to recent increases in food prices. The intensive farming schemes, the deforestation and the long distance transport of biofuels caused in some cases more emissions and energy consumption than fossil fuels, on a lifecycle perspective. Besides, having been mainly used as transport fuel, the final product and its exploitation did not influence positively the conditions of rural poor or their lack of modern energy sources (Dufey 2006; Von Braun & Pachauri 2006).

Main research activity has therefore directed towards the study of new sustainable form of interaction between bioenergy and food productions. Most of this activity focused on innovative energy crops, technologies, and production schemes, to be adopted in order to limit food vs. fuel competition. Little research has been done on the energetic exploitation of biomass wasted along food production and consumption chain and its impacts on the economic and environmental burden of agriculture.

3 Methodology

3.1 Life Cycle Assessment and the LCA in the agro-food sector

The focus on the relation between energy consumption and waste generation in the agro-food sector as a whole suggested to undertake an analysis with a full chain perspective. This choice allowed to overcome the general sectorial division of energy statistics and to account for all the impacts related to a single food product. In this way in fact, it is possible, for example, to attribute to a peach nectar all the energy inputs related to cultivation, processing, production of packaging, distribution, and waste treatment.

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This perspective is usually classified under the category of "*Life Cycle Thinking*" (LCT), a specific approach to environmental impacts analysis, emerged between the 60s and the 70s, mainly because of the increasing awareness of natural resources exhaustion. Since then, LCT gradually became a crucial analytical and decisional tool, especially because it allowed to overcome the usual focus of environmental policies on the minimization of single pollution sources, towards a measurement of the effects of the entire products life cycle, from raw material extraction to the end-of-life treatment. This new concept proved decisive to avoid the so called "*burden shifting*", meaning the compensation of the reduction of impacts in one chain, or in a single segment or geographical area, or in a single environmental sector with the contemporary increase of impacts in other chains, segments, etc.(EU JRC 2010; UNEP SETAC 2004). One example could be the use of biodiesel from palm oil, which is considered an effective way to reduce CO2 emissions from transport, but could also cause intensive cultivation, irrigation, pesticides, etc. The analysis of the environmental impact of this kind of innovations cannot therefore disregard a life cycle perspective and multiple different indicators.

The main tool for the measurement and assessment of environmental impacts of the life cycle of products is Life Cycle Assessment (LCA). LCA is a method of analysis which allows to quantify the "damage" of a product from "cradle to grave", reporting all the physical exchanges between the production system and the environment, in terms of inputs of resources used (materials, land, energy) and outputs of waste and emissions released into water, air and soil (EU JRC 2010). Food sector has one of the largest energy intensity, with inevitable consequences also on the evaluation of greenhouse gas emissions. In addition, the intensive use of pesticides, fertilizers and irrigation causes significant environmental impacts, ranging from eutrophication, soil erosion, fresh water consumption. At the same time, consumers show a greater attention to the impact of their food consumption not only in environmental terms, but also in terms of food safety. For these reasons, the measurement of environmental impacts, and especially LCA, has gained increasing importance in the food system, both in the academic and decision-making sectors, as well as in enterprises. In fact, given the close link between food systems and environment, LCA has important advantages in terms of analysis, as the full chain perspective, the ability to monitor soil fertility, the relationship between input and yields, the measurement of the impacts of alternative models of food consumption, the comparison between different production systems, the burden of transportation, distribution and packaging, or the disposal of waste and byproducts (Neri 2009; Roy et al. 2009).

This methodology has been developed by the Society of Environmental Toxicology and Chemistry (SETAC) in 1991 and later standardized by the International Organization for Standardization (ISO), in the UNI EN ISO 14040:2006 and UNI EN ISO 14044:2006 (ISO 2006a; ISO 2006b). These standards specify in detail the steps that must characterize an LCA:

- definition of goals and objectives,
- analysis of the life cycle inventory (LCI),
- impact assessment (LCIA),
- interpretation of results and suggestions for improvement.

In the first step, what has to be defined is: the objectives of the study (eg. comparison between conventional and organic products), the function(s) of the production system under analysis (what is produced) and its boundaries (inclusion or exclusion of certain processes and/or flows), the functional unit, the characteristics of data (databases, literature, environmental product declarations, questionnaires, private firms, etc.), assumptions and its limitations of the analysis and the method or methods of calculation used (developed by various organizations, institutions and companies) (Neri 2009).

In the LCI, all the processes that make up the system studied are identified: for example in the case of a fruit juice, all processes of cultivation, transformation, etc.. Then flows of resources, materials and energy, which are the input of the system, and all the emissions in the various environmental compartments (air, water and soil) as well as the end of life waste are measured. Usually the analysis of inventory starts with the representation of the system in a flow diagram, in which all stages of the life cycle are depicted as boxes connected by arrows depicting flows of materials or energies, and then it proceeds with the collection and processing of data (Neri 2009).

The evaluation of impacts is the objective of the third phase, the LCIA. Through the use of indicators internationally recognized and software, data from the LCI are "translated" into measures of the environmental hazard of the analyzed system. To this end, inventory data are first classified in specific impact categories, such as global warming, eco-toxicity of water and soil, potential depletion of resources, etc.. For example, data on the consumption of electricity from the network, and the corresponding production and distribution, are classified in global warming (greenhouse gas emissions), non-renewable energy (consumption of oil, coal, uranium), respiratory inorganics (particulate emissions) and so on. In turn, these categories are related to macro-areas, called damage categories, which refer to resource depletion, human health and environmental conservation. After the classification, impacts are quantified and aggregated in their respective categories through specific weighting or characterization factors. For example, the indicator "global warming", all the different greenhouse gases emitted by the system are converted using a coefficient, known as "global warming potential" (GWP), measured in kg CO2 eq, and then summed to obtain the so-called carbon footprint. Similarly, for the indicator "Non-renewable energy", the characterization factor is constituted by the calorific value of the forms of primary energy (typically fuels) used, measured in MJ per unit of substance (kg of oil, etc..). In all the evaluation methods used for the LCIA, characterization includes the impact categories. In some cases, however, the characterization also includes the categories of damage: in these cases, the impacts relating to a single category of damage are further converted, through damage factors, in measurement units that allow to evaluate the damage in several terms such as years of life lost (human health) or endangered species (ecosystem quality) (Neri 2009).

While the classification and characterization are key requirements of each LCIA, there are two other phases equally important, although not mandatory: standardization and evaluation (or weighing). The first consists in comparing the values obtained from the characterization with reference values, in order to make possible the comparison between different categories. Typically the normalization is obtained by dividing the specific impacts for the total impact relative to a reference sample, which may be the single nation, Europe or the world. In the case of IMPACT2002+, in the normalization of the category "Climate change", the normalization factor is equal to 9950 kg CO2 eq, representing the annual per capita emissions in Europe. The second phase which can be found in some LCA is the evaluation, which consists in assign different weights (evaluation factors) at each impact, according to different perspectives cultural importance of certain categories compared to other (Neri 2009).

The last phase of the LCA consists of the interpretation of the results and evaluation of improvements. In this phase the results arising from the LCIA are analyzed in order to detect the main environmental and highlight segments or processes of the life cycle which have room for improvement. At this stage it is also possible to check the reliability of the study through the so-called sensitivity analysis, which allows to evaluate the influence of the data on the final results and to make comparisons with alternative scenarios (Neri 2009).

3.2 Objectives and boundaries of the system analysed

In this research, as already mentioned, the objective of the study has been the comparison between a conventional peach nectar chain and an hypothetical case where in each segment of the production wastes are recovered for the production and self-consumption of bioenergy. The function of the systems is the production of peach nectar, but in the second system, bioenergy represent a co-product, which is consumed in the system itself. In both cases, the system boundaries included all the processes from raw material extraction, to the final disposal of peach nectar, its packaging and other waste. Likewise, the functional unit studied has been 1l of peach nectar. As far as methods of analysis are regarded, it has been chosen the method IMPACT2002+, modified to include a new indicator on the human health impact of wasted food calories, and two indicators estimating the quantity of active ingredients of pesticides emitted in the food chain.

SCHEMA INTEGRATO VS NN INTEGRATO

3.3 Data sources and collection (also in 4 and 5)

For the identification of the major processes, Fideghelli& Sansavini(2005) has been used as reference. For the integrated chain, the co-production and self-consumption of energy has been included according to two different perspectives: as avoided products and as co-products. Both the scenarions have been then confronted to the conventional chain.

Data have been collected mainly through literature review, regional production regulations, technical sheets of machineries, processes from EcoInvent database, and, in some case, new created processes. Some assumptions have been made on missing data.

3.4 Impact method/s choice and modifications

In this study, the LCIA has been conducted both for the conventional chain and for the comparison with the integrated chain (in the two perspectives above mentioned).

In this study, following the method chosen, the LCIA included the normalization and the weighting, leading to a translation of characterization results into points of damage. Furthermore, a sensitivity analysis has been conducted for the conventional chain, focusing on alternative of waste treatment. Finally, the bioenergy co-produced by the integrated chain has been compared to the respective fossil-based electricity and heat, in order to evaluate the differences of the impacts.

3.5 The end-of-life of wastes and residues

4 Life cycle assessment of the conventional peach nectar chain

The present chapter presents the complete LCA of a conventional peach nectar chain, according to the ISO standards (ISO 2006a; ISO 2006b). The first paragraph reports the analysis of inventory, with the description of the various processes composing the 4 segments of the chain, including all the data on inputs, outputs and emissions. The second paragraph presents the assessment of impacts according to the method described in the previous chapter. In the third paragraph it is included a sensitivity analysis between 2 options of waste management (conventional vs. recycle of materials). A final paragraph aims at discussing the main results of the LCA, with a specific focus on energy consumption, the impact of food waste and residues, and the effects of their treatment.

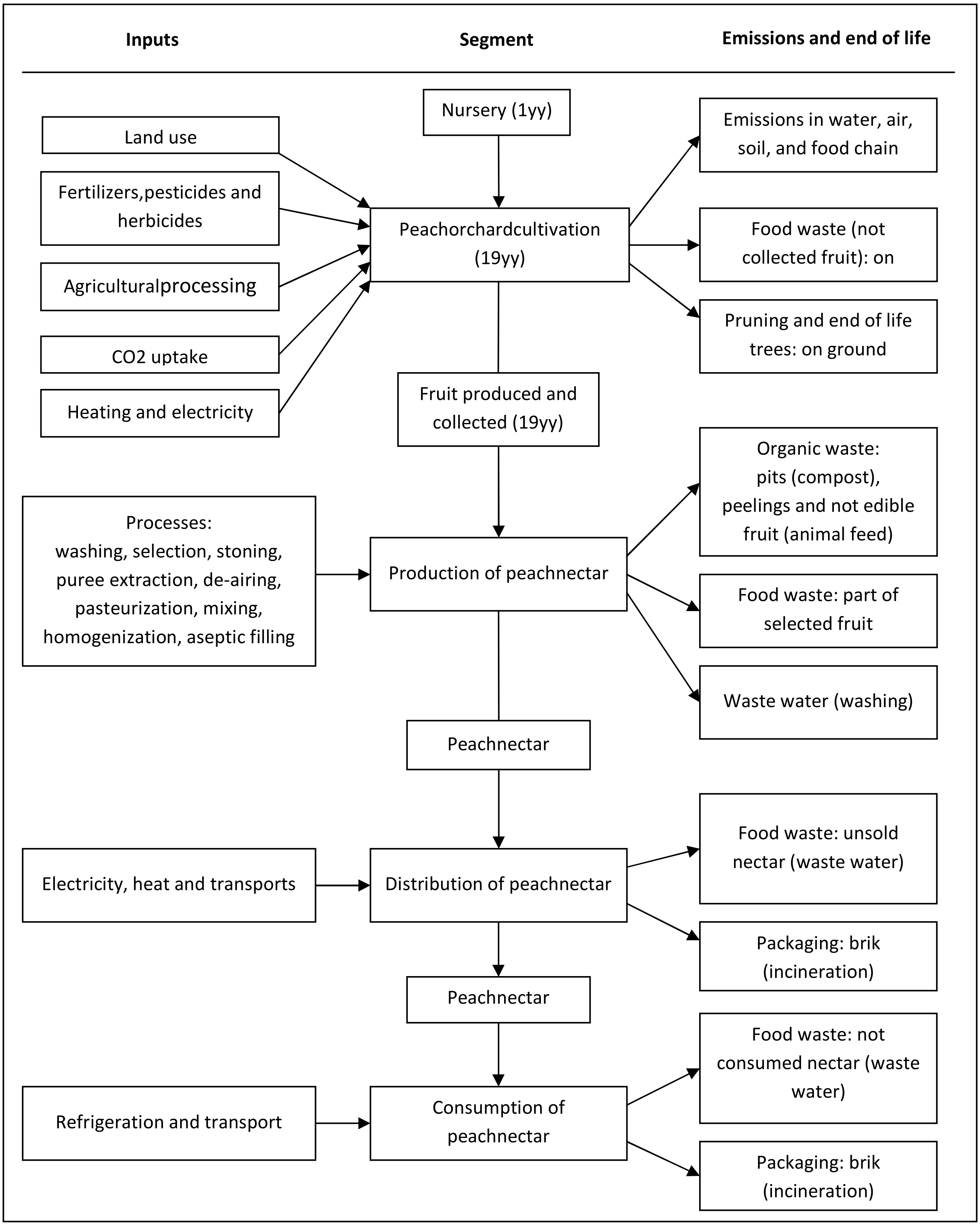
4.1 Inventory analysis (LCI)of the conventional peach nectar chain

The conventional peach nectar chain has been represented with a single process,Peach nectar, farm to fork, composed of 4 sub-processes, representing each segmentof the chain, from cultivation to consumption (Tab. 4.1). The *functional unit* of this process is constituted by the total volume of 3623,4 l of peach nectar consumed. In figure 2.1 the flow chart is represented, while the complete inventory for each sub-process is presented in the following sections.

Tab. 4.1 The process Peach nectar, farm to fork

Product/s	**Amount**	**Unit**	**Notes/Functional unit (FU)**
Peach nectar, farm to fork	3623,4	l	Net peach nectar volume consumed = 3660 briks of 1l x 0,99 (1% waste) = 3623,4 l.
Materials/fuels			
Peach, at conventional farm (with sub-processes)	2,6282	ton	Peach cultivated which are used in processing. Peach produced in 19yy life of orchard = 240 ton
Peach nectar, at conventional plant	3697	p	Peach nectar briks produced and sold to the distributer. Nectar produced out of 2.6282 tons of peaches.
Peach nectar, at large supermarket	3660	p	Peach nectar distributed and sold. Net peach nectar sold = 3697briks of 1l x 0.99 (1% waste) = 3660 p.
Peach nectar, consumed at house	3623,4	l	Peach nectar bought and consumed. Nectar consumed = 1 brik of 1l bought x 0.99 (1% waste) = 0.99 l.

Fig. 4.1 The flow chart of conventional peach nectar chain



4.1.1 Peach cultivation

The first segment of the conventional peach nectar chain is constituted by the cultivation of peaches in an orchard. This agricultural stage has been represented with a single process (Peach, at conventional farm (with sub-processes)) (see tab. XX for details), which includes all the productive inputs, the emissions, and the outputs related to the 19 years long life cycle of the orchard plus 1 year of nursery. The *functional unit*of the process is constituted by the total production of 240tons of peaches(Cerutti et al. 2010).

Tab. 4.2 The process Peach, at conventional farm (with sub-processes)

Products	Quantity	Unit	Comment/Notes
Peach, at conventional farm (with sub-processes)	240	ton	*Functional unit*: peach production over 19 years of orchard lifetime, calculated basing on (Cerutti et al. 2010): - 0 tons from year 0 to year 3 (year 0 is the nursery) - Increasing from year 4 to year 5 = 8t/ha*a - Constant from 6 to 18: 16t/ha - Decreasing from year 19: 8t/ha*a = Year 19
Resources			
Occupation, permanent crop, fruit	19	ha*a	Orchard lifetime: 19yy per 1 ha
Transformation, from pasture and meadow, intensive	0,29	ha	Original land use as pasture: 29%
Transformation, from arable, non-irrigated	0,71	ha	Original land use as not irrigate arable land: 71%
Transformation, to permanent crop, fruit	1	ha	Total land use: 1ha
Energy, gross calorific value, in biomass	284127,3	MJ	Total wood produced over the lifetime, calculated as: - Average trunk height: 0.60m with a section area of 0.0102m2 (Branzanti & Ricci 2001, p. 168); 3 main branches (lenght: 1.5m and section area: 0,0051m2); a further 10% of small branches, of which the 50% is cut each year; Wood density with 70% wet content: 900kg/m3; Roots, assumed to be the 25% of the total weight (Branzanti & Ricci 2001, p. 2) Total number of trees/ha (Fideghelli & Sansavini (eds.) 2005, p. 119): - Distance between the row: 5m - Distance between the threes: 3m - Number of threes: 666.66 Higher heating value: 7.2MJ/kg
Carbon dioxide, in air	21704,17	kg	Total CO2 uptake, calculated as function of carbon content in the wood: - Fresh wood weight: 39462kg - Dry wood weight: 39462*0.3 - Carbon content: 0.5kg/kg
Wood, hard, standing	43,84681	m3	Total wood volume

Peach wasted	4,8	ton	A 2% waste of uncollected peaches is assumed. In this process, this amount is simply reported as food waste and it is assumed to be left on the soil.
Materials/fuels			
Peach tree, at nursery	666,66	p	In this process, it is accounted all the damage related to the nursery process.
Electricity/heat			
Sub-process Fertilization	240	ton	This process includes only the various inputs
Sub-process Agro-processing	240	ton	This process includes only the various inputs
Sub-process Pesticides	240	ton	This process includes only the various inputs
Electricity, low voltage, at grid/IT U	6935	kWh	Electricity consumption: 1 kWh per day per year is assumed, to account for the energy consumption of a shed
Heat, natural gas, at boiler condensing modulating >100kW/RER U	1058832	MJ	Heat consumption, calculate assuming a shed (3*4*3m) heated for 2h/d for 3 months/yy
Social issues			
Recoverable food calories	1296000	kcal	Food calories waste with a 2% uncollected peach

The main*inputsfrom nature*included in the inventory are:

- Land occupation and land use change: given the orchard life cycle, an occupation of 19 ha*y has been considered; it has been supposed that the original land was already used partly as pasture (29%) and partly as arable irrigated land (71%), and then converted to the cultivation of a permanent crop (fruit);
- Biomass produced, in terms of energy (gross calorific value): the volume of fresh wood produced (including prunings, roots and the end of life of tree) has been estimated basing on Branzanti & Ricci(2001) and then multiplied by its density of 900kg/m3 (for a 70% wet content) (Francescato, Antonini & Mezzalira 2004), and by its gross calorific value(7.2MJ/kg)and the total number of trees, estimated basing on Fideghelli(2005, p. 119);
- CO2 uptake: it has been estimated basing on the carbon content of dry wood.

The main *inputsfromtechnosphere (materials/fuels)*are the young peach plants produced at the nursery, represented by the process Peach tree, at nursery. This process includes all the productive inputs needed to produces a 1 year old peach tree, including the pot and its processing, electric pump irrigation, water, laces and support rods, seeds, fertilization, applicationof plant protection products, transport of various inputs, all the emissions in air, water, and soil, and the end of life of pot, laces and rods.

As far as *inputsfrom technosphere(electricity and heat)* are regarded,the energy consumption of a small shed have been included, whilefertilization, agricultural processesand the applicationof plant protection products have been synthetized in 3 sub-processes, namely Sub-process Fertilization, Sub-process AgroprocessingandSub-process Pesticides. These processes includes processes, materials (fertilizers, pesticides, herbicides), packaging (sacs and bottles), transports and waste treatments (recycle of not contaminated plastic, incineration of hazardous plastic). As far as fertilizers and plant products are regarded, the products have been selected basing on the Regional Integrated Production Disciplinaries(Regione Emilia Romagna 2012).

As already detailed in the previous chapter (see par. 103.3), the related process *emissions in air, water, and soil* have been calculated basing on the Ecoinvent 2.2 database(ecoinvent Centre 2007) as far as fertilizers and heavy metals are regarded. For the estimation of the emissions deriving from pesticides (active substances), the specific amount for each substance and compartment has been calculated basing on the Mackay distribution principle, provided by the ISPRA plant products online database(ISPRA n.d.).

As far as food waste impact is regarded, among the *social issues*, it has been included the indicator “recoverable food calories”, which measures the amount of food calories lost because of food waste. In this process, it has been supposed that the 2% of total edible peaches are not collected. According to the amount of calories per 100g of fresch peaches (INRAN n.d.), it has been calculated the total amount of calories wasted. This data is then considered by the modified Impact method, in order to derive the impact in terms of **Human health**. Furthermore, in the same category it has been included a portion of 5% of the total emissions of pesticides in the vegetable biomass compartment, in order to estimate the quantity of active ingredients that could end in the food chain.

Finally, as residues treatment is regarded, in this process, it has been considered as conventional treatment, the disposal on the ground of both prunings and wasted fruit. Nevertheless, it has not been possible to collect neither primary or secondary data on the related emissions and the following impacts in terms of soil fertility (organic matter), as well as heavy metals and pesticides content in the various parts of the vegetable biomass.

4.1.2 Nectar production

The second phase of peach nectar chain is constituted by the transformation of peaches into fruit nectar. In order to identify the various processes as well as inputs required, this segment of the chain has been schematized basing on Fideghelli&Sansavini(2005). The related process (Peach nectar, at conventional plant) includes all the inputs in terms of energy, water, ingredients, and packaging materials, as well as all the emissions related to the processing steps needed to produce 3697 Tetra Brik (1 lt volume) of peach nectar, which is thus the *functional unit* (Tab. 4.3)

Tab. 4.3 The process Peach nectar, at conventional plant

Products	**Quantity**	**Unit**	**Functional unit/Notes**
Peach nectar, at conventional plant	3697	p	Functional unit: production of 3697 briks of 1l of nectar, for which 2,6282t of peaches have been used. The production of nectar implies the generation of 4 amounts of waste, which are considered for the end of life treatment.
Electricity/heat			
Peachwashing	2,628234	ton	FU calculated on the hypothesis that the selection implies a 2% waste referred to the amount of peaches that go into the stoning machine.
Peach selection	2,5767	ton	FU of the process calculate on the base of whole peaches weight.
Peach stoning	2,422098	ton	FU constituted by the weight of half peaches
Stoned peach selection	2,373658	ton	FU constituted by the weight of half peaches
Peach puree extraction	2,278752	ton	The FU is equal to the quantity of puree that can be extracted from the stoned peaches
Puree de-airing	2,2788	ton	FU: amount of puree de-aired
Pasteurization	2,2788	ton	FU: amount of pastorized puree
Acqueous solution mixing	1,848475	ton	FU: amount of acqueous solution mixed
Peach nectar mixing	4,1273	ton	FU: amount of puree and acqueousslution mixed
Puree de-airing	4,1273	ton	FU: amount of nectar de-aired
Peach nectar homogenization	3,696972	m3	FU: volume of nectar homogenizated (density equal to 1,1164 t/m3)
Pasteurization	4,1273	ton	FU: amount of nectar pastorized
Aseptic filling	3696,972	p	FU: number of 1l briks packaged
Nectar transformation waste recycle	0,195978	ton	Treatment of residues (except those deriving from stonig):

(coprod)			animal feed production. FU: amount of treated waste (co-product of a multioutput process)
Social issues			
Recoverable food calories	7099,032	kcal	si suppone che il 50% delle pesche cernite sia recuperabile a fini alimentari
Waste to treatment			
Compostingorganicwaste/RER U (da Composting NL 1995 (sub) di IVAMLCA3)	0,154602	ton	Treatment of residues from stoning: composting.

The processing phase is thus composed of the following production processes:

- Peach washing: this process includes water consumed and its disposal, a washing machinery, its transport, and the consumption of electricity;
- Peach selection:this process includes a conveyor belt, its transport and its electricity consumption;
- Peach stoning: this process includes the fruit stoner (based on the model OMIP K7-2008,(OMIP n.d.)), its transport, and the related water, compressed air and electricity consumption;
- Stoned peach selection: this process is similar to the previous, except for the functional unit, which is constituted by half peaches rather than whole peaches;
- Peach puree extraction: in this process, stoned peaches are transformed in a puree through a cold extractor (based on the model Giubileo, made by Rossi & Catelli(Rossi & Catelli n.d.)), its transport, as well as water and electricity consumption;
- Puree de-airing: the extracted puree is then subject to a de-airing process, which includes the deaeration unit (based on the model DA 2000 GEA Process Engineering), its transport, and the consumption of liquid carbon dioxide and electricity;
- Pasteurization: the puree is then pasteurized, through a sterilizer (based on the model Olimpic TC made by Rossi & Catelli(Rossi & Catelli n.d.)); in this process also the related transport, water, steam and electricity consumption are included;

- Aqueous solution mixing:in order to obtain a nectar with a 50% minimum of fruit content, an aqueous solution, containing a 90% water and a 10% syrup at 62° Bx[1], is added to the puree: “the syrup is obtained by mixing a 70%of sucroseorsugarcanesolution at 55°Bxand a 30% of glucose solution at 75°Bx, to whichare addedascorbic acid(antioxidant) andcitric acid(acidity regulator)”(Fideghelli &Sansavini (eds.) 2005, p. 231). This process represent the mixing of the solution, thus it includeswater, the Mixer, its electricity consumption, the Glucose, the sugar (from the database process Sugar, from sugar beet, at sugar refinery) and the transport of the machinery and the ingredients;
- Peach nectar mixing: in this process, the aqueous solution is mixed with the puree; also in this process it is included the mixer, its transport, and electricity consumption, but the functional unit is different from the previous process;
- Puree de-airing: in this process the nectar obtained is de-aired;
- Peach nectar homogenization: this process represent the homogenization of the nectar and it includes the machinery (based on the model BEEI DeBEE 2000P-100/45(BEEI n.d.)), its transport and its electricity consumption;
- Pasteurization: in this phase the nectar is pasteurized in order to prepare it for the filling;
- Aseptic filling: it is the final process, related to the filling of Tetra Briks, and it includes the aseptic filler (based on the model NSA made by IPI(IPI n.d.)), its transport, electricity, cooling water, steam and compressed air consumption, as well as the production of the packaging (represented by the modified database process Production of liquid packaging board containers, at plant/RER U (con riciclodegliscarti)[2]).

As far as the various residues and their disposal are regarded, in the conventional processing phase, the following treatment options have been considered as the common ones:

- Composting of peach stoning residues, which is represented by the processComposting organic waste/RER U (da Composting NL 1995 (sub) di IVAMLCA3) and is included in the “waste to treatment” compartment;
- Recycle of the remaining waste and residues as feedstock for the production of animal feed, through the processNectar transformation waste recycle (coprod), a multioutput process that leads to the following outputs (energy allocation): Nectar transformation waste recycle (coprod), the actual recycle

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[1] “Degrees Brix (symbol °Bx) is the sugar content of an aqueous solution. One degree Brix is 1 gram of sucrose in 100 grams of solution and represents the strength of the solution as percentage by weight (% w/w)” (Wikipedia 2012)

[2] The original process is included in the Ecoinvent database and it has been modified with the inclusion of the recycle of waste materials (1% estimation). As far as functional unit is regarded, the weight has been calculated in the process. The packaging has been modeled basing on the 1lt aseptic multilayer package made by IPI (http://www.ipi-srl.com/it/prodotti/contenitore-asettico/multistrato.html)

of wastes, and Flour for animal feed, which is the dried fruit flour to be used as animal feed (process based on Rape meal, at oil mill/RER U). The first one is thus used as end-of-life treatment, despite it is included among the inputs.

Finally, among the*social issues*, it has been included the indicator of food waste, supposing that the 50% of the discarded peaches in the selection process are recoverable for food purposes.

4.1.3 Nectar distribution

The distribution of peach nectar has been schematized basing on the methodology used in the database LCAfood (Nielsen et al. 2003),which includes the transport of food products and a mix of energy consumption (heat and electricity) calculated for different size of retailers. The energy mixture has thus been modified accordingly to the Italian energy mix. In the specific, the distribution is represented by the processPeach nectar, at large supermarket, whose *functional unit* is constituted by the 3660 briksof 1ltof peach nectar (Tab. 4.4Tab. 4.4 The process Peach nectar, at large supermarket).

Tab. 4.4 The process Peach nectar, at large supermarket

Products	Amount	Unit	Functional unit/Notes
Peach nectar, at large supermarket	3660,03	p	FU: amount of nectar sold. It is assumed a 1% of unsold nectar which is treated as waste
Resources			
Peach nectar wasted	41,27331	kg	This input represent the amoun of unsold nectar, which is assumed to be the 1% basing on the average food waste in the distribution (between the 0,7 andthe 1,2 % of the sector income
Electricity/heat			
Transport, lorry 20-28t, fleet average/CH U	412733,1	kgkm	Transport of the nectar for 100 km from the processing plant
Retail (long time stor., room temp., large store) (IT)	4127,331	kg	It represent the electricity and heat needed for a 1kg of goods distributed
Social issues			
Recoverable food calories	23938,52	kcal	Food wasted in the distribution. The amount of calories has been estimated basing on the the value of 58 kcal per 100g of nectar(Valfrutta n.d.)

Waste to treatment			
Disposal, polyethylene, 0.4% water, to municipal incineration/CH U	0,503487	kg	Incineration has been considered as the conventional treatment of wasted packaging. The amount has been calculated basing on the number of briks and the weight of each materialderived from the process Production of liquid packaging board containers, at plant/RER U (con riciclodegliscarti).
Disposal, aluminium, 0% water, to municipal incineration/CH U	0,119634	kg	Incineration of aluminium
Disposal, packaging cardboard, 19.6% water, to municipal incineration/CH U	1,771115	kg	Incineration of cardboard
Treatment, sewage, to wastewater treatment, class 2/CH U	0,03697	m3	End of life of the unsold nectar is assumed to be the sewage water

The process includes the transport on lorry of the nectar from the processing plant to the supermarket and the energy consumption represented by the processRetail (long time stor., room temp., large store) (IT), (in which are synthetized the amounts of heat and electricity consumed per kg of distributed products).

As far as waste and related treatment are regarded, it has been hypothesized that the 1% of the total nectar purchased by the retailer is not sold before the date of expiry. The hypothesis is based on the average data on food waste as a percentage of large scale distribution turnover, which is comprised between the 0,7 and the 1,2%. This waste has been taken in consideration both for the end-of-life treatment (nectar in the sewage system and packaging in the municipal incinerator) and for the recoverable food calories.

4.1.4 Nectar consumption

The segment representing the household consumption of peach nectar has been structured basing on the methodology used in the database LCAfood, which, in the case of food products that requires refrigeration, includes different categories of fridge. In the specific, the consumption has been represented through the process Peach nectar, consumed at house, with a *functional unit*of 0,99lt of peach nectar consumed. In fact, in order to account for food waste, it has been assumed that a 1% of the nectar is not consumed before the date of expiry. The process thus include the transport of the nectar from the supermarket to the house with a passenger car and the energy consumption of the fridge, for the 3 days of conservation after the opening of the brik, represented by the processRefrigerator, small, A (IT), which is a modification of the original database process with the national electricity mix.

As the residues and the packaging end-of-life treatment are regarded, it is assumed that the nectar wasted is thrown in the sewage, while the brik goes to the municipal incinerator. The nectar wasted is also taken in consideration for the amount of recoverable food calories. The process is reported in the following table (Tab. 4.5).

Tab. 4.5 The process Peach nectar, consumed at house

Products			
Peach nectar, consumed at house	0,99	l	FU: consumption of 1 brick of nectar per a total volume of 0,99l, including a 1% waste
Resources			
Peach nectar wasted	0,011164	kg	A 1% wasteisassumed
Electricity/heat			
Transport, passenger car/RER U	0,6	personkm	It is assumed a weekly purchase of 50 €, which includes a brik of 1,50€; transport is then economically allocated:1p*10km*2trips*1,5/50
Refrigerator, small, A (IT)	3	l*day	Fridge use: 3dd (expiry date after opening)
Social issues			
Recoverable food calories	6,47512	kcal	Food kcal calculated as in the distribution segment, considering a 1% waste
Waste to treatment			
Disposal, polyethylene, 0.4% water, to municipal incineration/CH U	0,013618797	kg	Calculated as in the distribution segment
Disposal, aluminium, 0% water, to municipal incineration/CH U	0,003235971	kg	-
Disposal, packaging cardboard, 19.6% water, to municipal	0,047906829	kg	-

incineration/CH U			
Treatment, sewage, to wastewater treatment, class 2/CH U	0,00001	m3	-

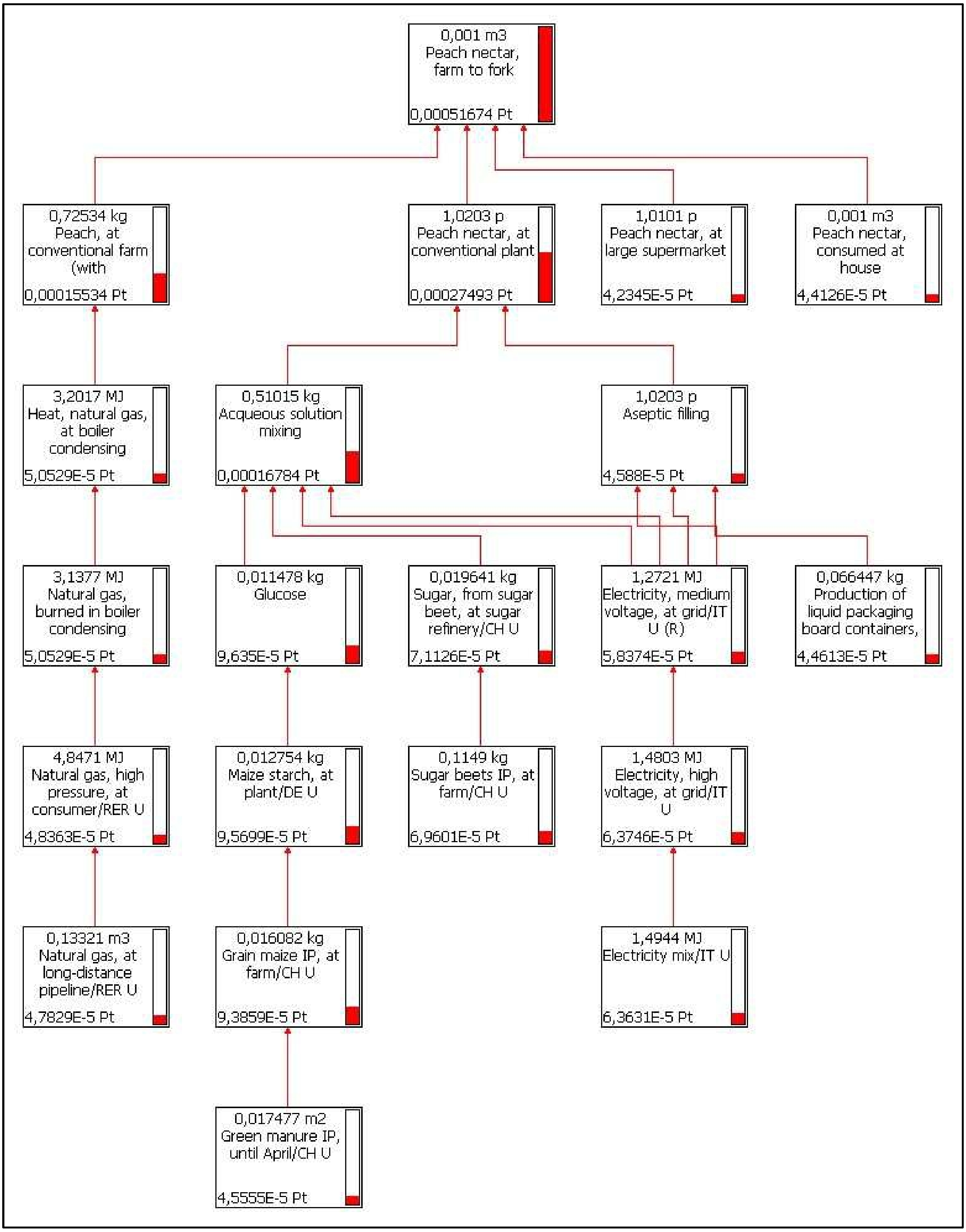
4.2 Impact assessment (LCIA)

In this paragraph, the results of the Life Cycle ImpactAssessment of the conventional peach chain described above are presented. The LCIA is referred to a functional unit of 1 lt of a produced, distributed, and consumed peach nectar. The method used for the calculation is “IMPACT 2002 versione 240412 (catena alimentare)”, which is a version of the original method IMPACT 2002, with the modification described in paragraph3.4. The process studied isPeach nectar, farm to fork (see par. 4.1), which is located in the database used at the following position: SimaPro3.3/Prof.originale/De Menna/fabio/processing/others/Peach Nectar.

In order to have a first insight of the impacts associated to the peach nectar chain, it is important to important to firstly analyze the network of the process, which is showed in Fig. 4.2. The figure helps to identify the relative contribution of the different sub-process in terms of single score damage. In each block of the figure it is reported the corresponding process, with an indication of both its functional unit and its absolute result in terms of damage. Given the high number of processes involved in the analysis, the cut-off has been set at 8,1% in order to guarantee an appropriate balance between relevance and visibility. This implies that in the network only processes with a relative damage contribution higher than the 8,1% are shown.

From the analysis of the network it is possible to derive the first indications regarding the main factors leading to the final damage. First of all, the segments with the higher impact are the transformation phase and the cultivation of peaches, with only a residual share of the distribution and final consumption. As far as the processing of nectar is regarded, the damage is largely imputable to the cultivation of feedstock needed for the production of ingredients, such as glucose and sugar, used in the syrup. Another part of the damage is caused by the aseptic filling, both because of the electricity consumption and of the package used. In the cultivation phase, the only process with a contribution higher than the selected cut-off is the heat consumption (in the shed), although it is possible to argue that there are other processes with slightly lower impacts.

Fig. 4.2 The network with a cut-off of 8,1% of the process Peach nectar, farm to fork



The detailed results of the LCIA are reported in the following paragraphs according to the classic structure of the various phases, from characterization to damage assessment, normalization and weighting.

4.2.1 Characterization

The first step in the assessment of impacts is represented by the characterization. This part of the analysis is crucial in order to classify the various flows identified in the inventory into different impact categories, and to measure the impacts of the multiple substances in common equivalence units. In the Tab. 4.6 the main results of the characterization are summarized.

Tab. 4.6 Characterization per impact category of the process Peach nectar, farm to fork

Impact category	Unit	Total	Peach, at conventional farm	Peach nectar, at conventional plant	Peach nectar, at large supermarket	Peach nectar, consumed at house
Carcinogens	kg C2H3Cl eq	0,015827	0,003005	0,007733	0,000655	0,004433
Non-carcinogens	kg C2H3Cl eq	0,019905	0,011289	0,002043	0,000736	0,005837
Respiratory inorganics	kg PM2.5 eq	0,000589	0,000139	0,000243	0,00011	9,71E-05
Ionizing radiation	Bq C-14 eq	13,60002	2,925947	6,176392	2,029649	2,468035
Ozone layer depletion	kg CFC-11 eq	5,21E-07	4,11E-08	4,5E-07	1,51E-08	1,54E-08
Respiratory organics	kg C2H4 eq	0,000383	6,79E-05	0,000155	4,18E-05	0,000119
Aquatic ecotoxicity	kg TEG water	3260,515	3175,676	69,86712	8,021357	6,951144
Terrestrial ecotoxicity	kg TEG soil	13,51787	7,341267	0,751115	3,224471	2,201022
Terrestrial acid/nutri	kg SO2 eq	0,015379	0,005075	0,005564	0,002528	0,002213
Land occupation	m2org.arable	2,895918	0,665325	2,224344	0,001152	0,005097
Aquatic acidification	kg SO2 eq	0,003324	0,000908	0,001342	0,000625	0,000448
Aquatic eutrophication	kg PO4 P-lim	0,310897	0,310716	0,000149	1,84E-05	1,46E-05
Global warming	kg CO2 eq	0,909408	0,316797	0,301009	0,136041	0,15556
Non-renewable energy	MJ primary	15,2671	5,268612	5,786957	2,269791	1,941736
Mineral extraction	MJ surplus	0,041815	0,005728	0,029816	0,003867	0,002405
Carcinogens in food product	kg C2H3Cl eq	0	0	0	0	0

Recoverable food calories	kcal	19,02318	3,916841	1,959218	6,606591	6,540525
Non-carcinogens in food product	kg C2H3Cl eq	5,5E-09	5,5E-09	0	0	0
Renew. energy	MJ	0,020289	0,00279	0,011356	0,00428	0,001864

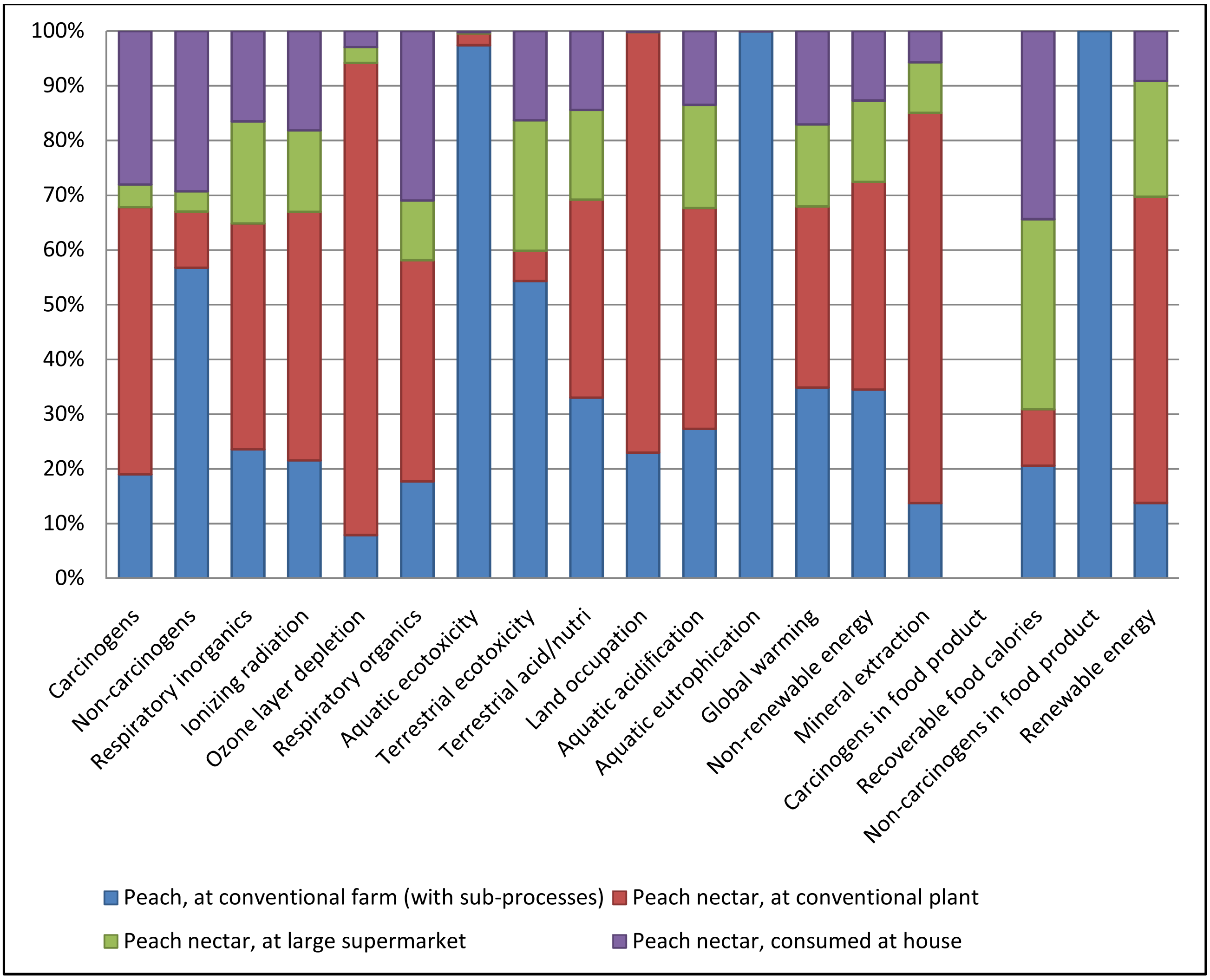
In the third column of the table, there are the total impacts per each category, while in the other 4 columns on the right there are the absolute impacts per each of the 4 processes representing the segments of the chain. In the following figure (Fig. 4.3)it is shown the contribution of the 4 main processes in percentage terms. As shown in the figure, the transformation phase represents the most impacting segment in most of the categories, in particular in **Carcinogens**, **Ozone layer depletion**, **Land occupation** and **Mineral extraction**, while its impacts are lower in **Non-carcinogens**, **Acquatic and terrestrial ecotoxicity**, and **Aquatic eutrophication**, where a relevant role is played by the cultivation phase. As far as the other two segments are regarded, the distribution has a quite relevant impact in **Respiratory inorganics**, **Terrestrial ecotoxicity**and **Recoverable food calories**, while the household consumption contributes to a certain extent in the categories **Carcinogens** and **Non-carcinogens**, **Respiratory organics** and **Recoverable food calories**.

Nevertheless, these results do not provide a complete insight on the factors, processes, as well as substances, leading to the mentioned impacts. In order to have a full picture of the impacts of the peach nectar chain is thus necessary to proceed, per each category, to a specification per substance and processes.

In the category **Carcinogens**, the total impact is equal to 0.015827kg C2H3Cl eq, largely caused (76.98%) by the emission of *Hydrocarbons, aromatic* in air, arising for the 47.57% from the process Peach nectar, at conventional plant and, in particular (for the 78.8%) from the Polyethylene, HDPE, granulate, at plant/RER used in the production of the Tetra Pak brik). Another relevant emission is represented by the *PAH, polyciclic aromatic hydrocarbons* in air which accounts for the 7.2% of the total, and is caused for the 77.36% by the process Peach nectar, at conventional plant and, in particular (for the 45.36%) by the Aluminium, primary, liquid, at plant/RER used in the production of the Tetra Pak brik).

In the category **Non-Carcinogens**, the total impact is equal to 0.019905kg C2H3Cl eq, and it is due to 5 substances. The emission that causes a large share of the damage (28.13%) is *Dioxin, 2, 3, 7, 8 Tetrachlorodibenzo-p-*, and it derives for the 81.46% from the waste treatment of the peach nectar packaging (94.68% from Process-burdens, municipal waste incineration/CH) in the household consumption. The second relevant emission is the *Cadmium* in soil (20.07% of the damage), totally deriving from the cultivation of the peach orchard). Another relevant share (18.1%) of the damage is caused by the emission of *Arsenic* in soil related to the composting of the organic waste of the processing phase (represented by the process Composting organic waste/RER U (da Composting NL 1995 (sub) di IVAMLCA3)). In the cultivation segment, the nursery causes the emission of *Fluvalinate* in water, which explains another 12.09% of the damage. Finally, the emission of *Arsenic ion* in water causes a share of 12.08%, and it is mainly due to the processing phase, related to the disposal of the so called red mud, a solid waste product of the bauxite production process needed for the production of aluminum.

Fig. 4.3 Diagram of the characterization of the process Peach nectar, farm to fork



The total impact in the category **Respiratory inorganics**is equal to 0.00058863 kg PM2.5 eq and it is caused mainly by 4 emissions. The first one is the emission of *Nitrogen oxides* in air (38.63%), mainly deriving from the processing phase, and in particular from the transport of inputs (Operation lorry, 20-28t, fleet average). The second relevant emission is constituted by *Particulates, <2.5 µm* in air, which causes the 21.78% of the damage, and is primary related to the production of aluminum (Aluminium, primary, liquid, at plant/RER), linked to the packaging. The emission in air of the *Sulfur dioxide*explains a 19.95% of the damage, and it is mainly related to the electricity consumption in the processing phase (it is caused by the combustion of heavy fuel oil in power plants). Finally, the emission in air of *Particulates, >2.5 µm, and <10µm* (mainly coming from the processing phase and in particular from the extraction of bauxite) causes another share of the per il 7.76%. The**Ionizing radiation**impact (equal to 13.6Bq C-14 eq) is strictly related to the nuclear energy production chain. In particular, the 63.27% of the damage results caused by the emission of *Radon-222* in air (related to the tailings in the uranium milling) and is mainly linked to the consumption of electricity in the processing phase (45.91%). The 31.98% is caused by the emission of *Carbon-14* in air linked to the management of nuclear spent fuel. Also in this case, the consumption of electricity in the processing of peach nectar is the most relevant factor(44.45%).

In the **Ozone layer depletion** category, the total impact is equal to 5.2136E-7 kg CFC-11 eq, and it is caused mainly by the emission of *Methane, bromotrifluoro-, Halon1301* in air (80.51%), connected to the production of the packaging. Another 11.52% of the damage is then caused by the emission of *Methane, bromochlorodifluoro-, Halon1211* in air, which is mainly caused by the cultivation segment (for the 54.72%), mainly because of the heat consumption: in fact, this emission is related to the distribution of natural gas in the long distance pipeline.

The total damage of the **Respiratory organics**is equal to 0.00038338 kg C2H4 eq, and it is largely (86.79%) deriving from the emission of *NMVOC, non methane volatile organic compounds, unspecified origin* in air. The 43.13% of this emission is located in the processing phase, especially because of the production process of the packaging.

As far as **Acquaticecotoxicity**is regarded, most of the impact, amounting at3260.5kg TEG water, is caused by the emission of *Fluvalinate* in water, during the cultivation of peaches.

The peach orchard has a relevant influence also on the **Terrestrial ecotoxicity**total impact, equal to 7.0928 kg TEG soil. In fact, the main emission is the *Zinc* in soil, which explains the 52.47% of the damage and is almost totally deriving from the cultivation of peaches, which causes also the emission of *Cadmium* (9,02%) and *Nickel* (9%) in soil. Nevertheless, also the processing phase has a certain impact, especially for the emission of *Aluminium*in soil(17.97%), related to the waste treatment of drilling waste, and for the emission of *Aluminium* in air (14.58%), deriving from the blasting process. Furthermore, also the distribution of the nectar causes a small share of damage (6.86%) because of the emission of *Chromium VI* in soil deriving from the low voltage distribution of the electricity consumed.

In the category **Terrestrial acid/nutri**the total impact, equal to 0.015379 kg SO2 eq, is due mainly to the first two segment of the peach nectar chain. This is explained by the emission of *Nitrogen oxides* in air (63.96%) and *Ammonia* in air (25.97%), which are caused partly by the cultivation phase and by the processing phase (in the specific, processing is responsible for the 36,42% of the damage, and, in particular for the 11.38% byOperation, lorry 20-28t, fleet average/CH).

As far as land use is regarded, the whole chain causes an impact of 2.8959 m2org.arable in the category **Land occupation**. Despite the use of land for the cultivation of peaches, this impact is caused mainly by the processing of nectar. In fact, the 73.67% of the damage is due to the *Tranformation, to arable, non irrigated*, which is caused for the 99.87% by the processPeach nectar, at conventional plantand, in particular, by the cultivation of Green manure IP, until April/CH, used for the production of ingredients of the syrup. Thus, only a third (32.46%) of the damage is caused by the cultivation of peaches, in particular because of the *Transformation, to permanent crop, fruit*.

In the category **Aquatic acidification**, the total impact is equal to 0.0033241 kg SO2 eqand it is caused by the following air emissions: *Sulfur dioxide* (45.3%),*Nitrogen oxides*(37.74%), and*Ammonia*(15.1%).In **Aquatic eutrophication**, all the damage (0.3109 kg PO4 P-lim) is caused by the emission of *Phosphorus* in water during the cultivation phase.

As far as **Global warming**is regarded, the impact is equal to 0.90941 kg CO2 eq, mostly deriving from the emission of *Carbon dioxide, fossil* in air (90.79%), with a relevant role of the processing phase(33.57%), in particular because of the combustion of natural gas for the production of heat.

Likewise, in **Non-renewable Energy**, the consumption of heat and electricity in the first two segments of the chain is responsible of most of the total impact. The total consumption is equal to 15.267 MJ Primary and more than half of it is caused by the consumption of natural gas (56.58%), especially in the cultivation phase (50.47%): most of this impact (35.09%) actually comes from the onshore production of natural gas, thus from the indirect energy use. Another relevant share (25.74%) is attributable to the indirect consumption of crude oil, mostly in the processing of nectar (40.09%) and especially for the production of polyethylene in the packaging. Finally, the 9.06% of the non-renewable energy consumption is caused by the indirect consumption of uranium (and in particular its extraction), related to the consumption of electricity, especially in the processing phase (48.38%).In **Renewable energy**the total consumption is equal to 0.020289 MJ, mainly wind power (98.41%), used in large part (56.14%) in the processing phase.

As far as **Mineral extraction**is regarded, the total impact is equal to 0.041815 MJ Surplus, related to the extraction of various resources. The more relevant one is well water, which accounts for the 32.91% of the total, and in particular its consumption during the processing phase (87.3%) where many sub-processes require tap water (97.69%). Another 25.95% of the value is due to the consumption of cooling water, which is used mainly in the production of energy. In the specific, the 48.38% is due to the processing segment and in particular to the process Uranium natural, at underground mine/RNA (53.35%). The third important resource consumption is *Aluminium, 24% in bauxite, 11% in crude ore, in ground*, which accounts for the 17.55%, and is mainly caused by the processing of nectar (50.45%). A further 11.19% is due to the extraction of *Nickel, 1.98% in silicates, 1,04% in crude ore, in ground*, almost totally related to the cultivation phase (93.97%). Finally, another 9.29% is caused by the consumption of water in the production of the packaging (in the specific the 83.87% is determined by the processPeach nectar, at conventional plantand, in particular, for the 86.46% by the processLiquid packaging board, at plant/RER).

As far as **Carcinogens in food product** are regarded, the impact is equal to 0 because none of the phytochemicals substances used in the cultivation segment has been found as carcinogen. Nevertheless, some of those active ingredients have been found as non-carcinogens. In particular, in the **Non-carcinogens in food product** category, it is reported an impact of 5.5024E-9 kg C_2H_3Cl eq, due to *Fluvalinate* (90.23%), followed by *Myclobutanil*(9.77%).

Finally, the total number of food calories wasted, which is estimated by the category **Recoverable food calories**, is equal to 19.023 kcal per litre of nectar consumed. As showed in Fig. 4.3 Diagram of the characterization of the process Peach nectar, farm to fork, most of the impact is caused by the last two segments of the chain. In the specific, the distribution causes the 38.72% of food calories waste. Nevertheless, this estimation is clearly influenced by the large difference in terms of calories between the peach and the nectar.

4.2.2 Damage assessment

In this paragraph the results of the damage assessment are presented. This phase of life cycle assessment allows to measures the damage related to the impact of the product analyzed, in terms of general categories, such as human health, ecosystem quality, etc., converting each impact reported in the characterization into units of damage related. The Tab. 4.7 reports the main results of the damage assessment of one liter of peach nectar, per each impact category.

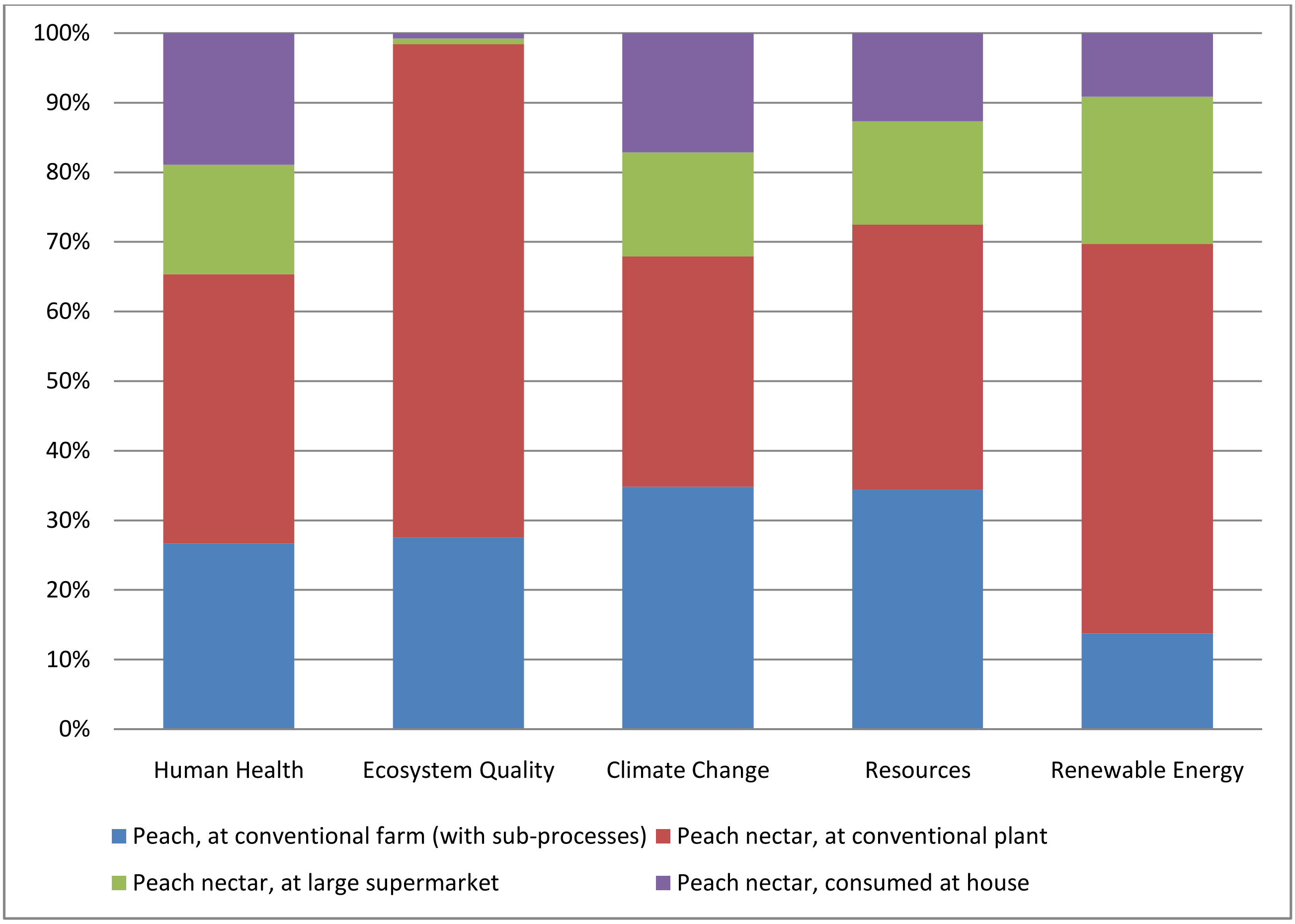
Tab. 4.7 Damage assessment per impact category of the process Peach nectar, farm to fork

Damage category	Impact category	Unit	Total	Peach, at conventional farm	Peach nectar, at conventional plant	Peach nectar, at large supermarket	Peach nectar, consumed at house
Human health	Carcinogens	DALY	4,43E-08	8,41E-09	2,17E-08	1,83E-09	1,24E-08
	Non-carcinogens	DALY	5,57E-08	3,16E-08	5,72E-09	2,06E-09	1,63E-08
	Respiratory inorganics	DALY	4,12E-07	9,7E-08	1,7E-07	7,69E-08	6,8E-08
	Ionizing radiation	DALY	2,86E-09	6,14E-10	1,3E-09	4,26E-10	5,18E-10
	Ozone layer depletion	DALY	5,47E-10	4,32E-11	4,72E-10	1,58E-11	1,62E-11
	Respiratory organics	DALY	8,17E-10	1,45E-10	3,3E-10	8,9E-11	2,53E-10
	Carcinogens in food p.	DALY	0	0	0	0	0
	Recov. food calories	DALY	5,39E-11	1,11E-11	5,55E-12	1,87E-11	1,85E-11
	Non-carcin. in food p.	DALY	1,54E-14	1,54E-14	0	0	0
Ecosystem quality	Aquatic ecotoxicity	PDF*m2*yr	0,163678	0,159419	0,003507	0,000403	0,000349
	Terrestrial ecotoxicity	PDF*m2*yr	0,106926	0,058069	0,005941	0,025506	0,01741
	Terrestrial acid/nutri	PDF*m2*yr	0,015994	0,005277	0,005786	0,002629	0,002302
	Land occupation	PDF*m2*yr	3,156551	0,725204	2,424535	0,001256	0,005556
Climate change	Global warming	kg CO2 eq	0,909408	0,316797	0,301009	0,136041	0,15556
Resources	Non-renewable energy	MJ primary	15,2671	5,268612	5,786957	2,269791	1,941736
	Mineral extraction	MJ primary	0,041815	0,005728	0,029816	0,003867	0,002405
Renewable energy	Renewable energy	MJ	0,020289	0,00279	0,011356	0,00428	0,001864

As for the characterization, in the third column it is possible to find the total impacts per each category, while in the other columns the absolute impacts per each of the 4 processes representing each segment. The use of common unit of measure for each damage categories allows to make comparisons between the related impact categories. In the case of **Human health**, the main impact category is **Respiratory inorganics** which causes the 79.8% of the total. As far as **Ecosystem quality** is regarded, the category **Land occupation** is the most relevant, explaining the 91.68% of the total. Finally, the highest damage in terms of Resources is due to the category **Non-renewable energy**, which causes almost all of the total (99.73%).

In the following figure (Fig. 4.4) the percentage contribution of the singlesegments per each damage category is shown.

Fig. 4.4Diagram of the damage assessment of the process <u>Peach nectar, farm to fork</u>



The processing of nectar represents the segment with the single highest impact in all the categories. In the specific, it causes the 38.67% of the damage in **Human health**, equals to 1.9967E-7 DALY, the 70.86% in

Ecosystem quality, equals to 2.4398 PDF*m2*yr, the 34.84% in **Climate change**, equals to 0.3168 PDF*m2*yr, the 38% in **Resources**, for a total of 5.8168 MJ primary, and the 55.97% in **Renewable energy**, equal to 0.011356 MJ. The cultivation of peaches remains the segment with the second largest impact in almost all the categories, except for **Renewable energy**. The distribution and the consumption segments represent an approximate 30% share of the damage in all the categories, with the notable exception of **Ecosystem quality**.

As far as substances are regarded, in **Human health** most of the damage is imputable to *Nitrogen oxides* (30.93%), to *Particulates, <2.5μm* (17.38%), to *Sulfur dioxide* (15.92%), and to *Hydrocarbons, aromatic* (6.6%). In **Ecosystem quality**, the land use causes most of the impact (67.54% due to *Transformation to arable, non – irrigated*, and 29.76% due to *Transformation, to permanent crop, fruit*), while a residual share of the damage is caused by *Fluvalinate* (4.26%). Finally, in **Resources**the 56.43% of the impact is due to*Gas, natural, in ground*, the 25.67% to*Oil, crude, in ground*, and the 9.04% to*Uranium, in ground.* .

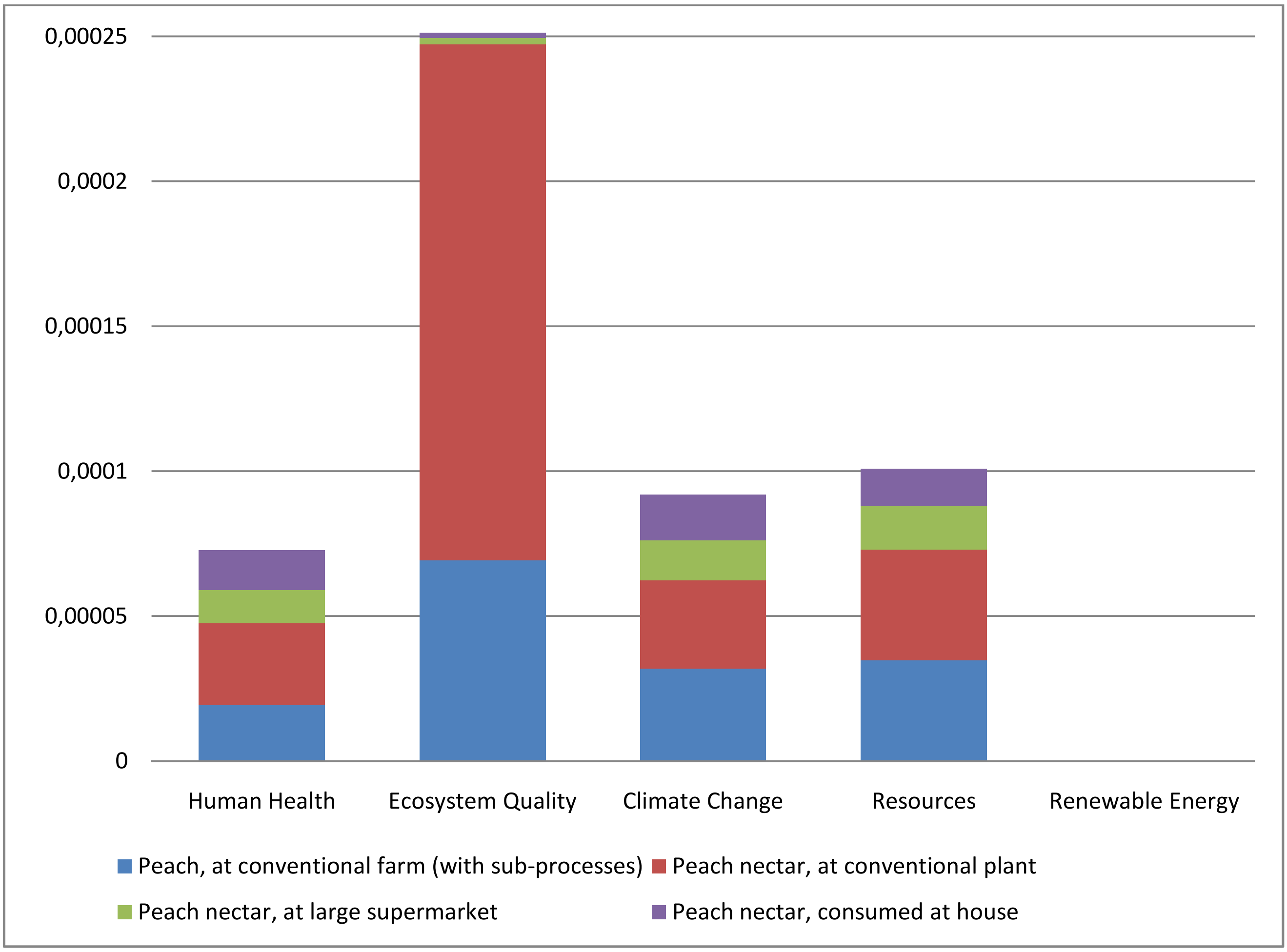
4.2.3 Normalization

In the normalization, the results of damage assessment are compared to the average damage of the human activities in a given geographical context. In the specific, as mentioned in Par. 3.4, in the case of IMPACT2002+, the damage in each category is confronted to the equivalent damage of the yearly European human activitiesdivided per the European population. Per each category, the damage of 1l of peach nectar has thus been compared to the damage of European activities for each citizen. The main results of the normalization are showed in Fig. 4.5, together with the relative contribution of the individual chain segments.

From the analysis of results, it is possible to argue that the category with the highest relative damage in respect to the reference population is **Ecosystem Quality**, with a ratio of 0.000251357, meaning that the impact of peach nectar chain is equal to 2,5 ten-thousandth of the entire damage produced in the same category by human activities in Europe in one year and referred to one citizen. The second category is constituted by **Resources**, where the damage on global resources is about aten-thousandth of the total of European activities per citizens (0.00010073 times). Similarly, in the **Climate change** category, the chain analyzed produces the equivalent of 9.185E-5 times the reference damage. As far as **Human Health** is regarded, the analysis shows that the damage caused is equal to 7.2807E-5 times the damage of European human activities. Finally, in the **Renewable Energy** category, the peach nectar causes 1.9434E-7 times the consumption of renewable energies of a single European citizen.

Coherently with the results of the previous paragraph, the processing phase represents the most relevant segment also if referred to the European context, while the cultivation of peach represents only the second source of damage. The distribution and the consumption segments play only a residual role, especially when Ecosystem Quality is considered.

Fig. 4.5 Diagram of the normalization (per damage category) of the process Peach nectar, farm to fork



In Tab. 4.8, results of the normalization per impact category, as well as per segment, are presented. In the specific, it is possible to note how the categories with the highest relative impact are **Land occupation**, **Non-renewable energy**, **Global warming**, and **Respiratory inorganics**. In the first case, most of the damage is caused by the processing phase, which is equivalent to 0,00018 times the reference damage. In the second category, both the cultivation and the processing phase produce a damage which is about almost 0,00004 times the consumption of non-renewable energy in Europe per year and citizen. Likewise, the damage produced by greenhouse gas emissions in the cultivation as well as in the processing segment is equal to 0,00003 times the reference damage. Finally, in the case of respiratory inorganics, the transformation of peaches in nectar causes the equivalent of 0,000024 times the reference damage.

Tab. 4.8 Normalization per impact category of the process Peach nectar, farm to fork

Damage category	Impact category	Total	Peach, at conventional farm	Peach nectar, at conventional plant	Peach nectar, at large supermarket	Peach nectar, consumed at house
Human health	Carcinogens	6,24841E-06	1,18628E-06	3,05313E-06	2,58713E-07	1,75029E-06
	Non-carcinogens	7,85856E-06	4,45698E-06	8,066E-07	2,906E-07	2,30438E-06
	Respiratory inorganics	5,80982E-05	1,3676E-05	2,39965E-05	1,08421E-05	9,5836E-06
	Ionizing radiation	4,02697E-07	8,66373E-08	1,82883E-07	6,00979E-08	7,30785E-08
	Ozone layer depletion	7,71872E-08	6,09042E-09	6,6578E-08	2,23341E-09	2,28537E-09
	Respiratory organics	1,15139E-07	2,03807E-08	4,65491E-08	1,25469E-08	3,56624E-08
	Carcinogens in food p.	0	0	0	0	0
	Recov. food calories	7,59553E-09	1,56391E-09	7,82273E-10	2,63787E-09	2,61149E-09
	Non-carcin. in food p.	2,17236E-12	2,17236E-12	0	0	0
Ecosystem quality	Aquatic ecotoxicity	1,19485E-05	1,16376E-05	2,56035E-07	2,93951E-08	2,54732E-08
	Terrestrial ecotoxicity	7,80563E-06	4,23907E-06	4,33716E-07	1,86191E-06	1,27094E-06
	Terrestrial acid/nutri	1,16758E-06	3,85257E-07	4,22408E-07	1,91897E-07	1,68021E-07
	Land occupation	0,000230428	5,29399E-05	0,000176991	9,16803E-08	4,05589E-07
Climate change	Global warming	9,18502E-05	3,19965E-05	3,04019E-05	1,37402E-05	1,57115E-05
Resources	Non-renewable energy	0,000100457	3,46675E-05	3,80782E-05	1,49352E-05	1,27766E-05
	Mineral extraction	2,75143E-07	3,76883E-08	1,96186E-07	2,54447E-08	1,58241E-08
Renewable energy	Renewable energy	1,94343E-07	2,6727E-08	1,08771E-07	4,09943E-08	1,78501E-08

4.2.4 Weighting and Single Score

The final phase of LCIA is the weithing and single score analysis, which are aimed at converting results from the previous phases into a single indicator of the process impact. In the specific, the results of normalization are weighted according to the selected method, and then summed up to identify the final scoreallowing for comparative analysis between impact, as well as damage, categories.In Tab. 4.9 results of the weighting per single score are shown.

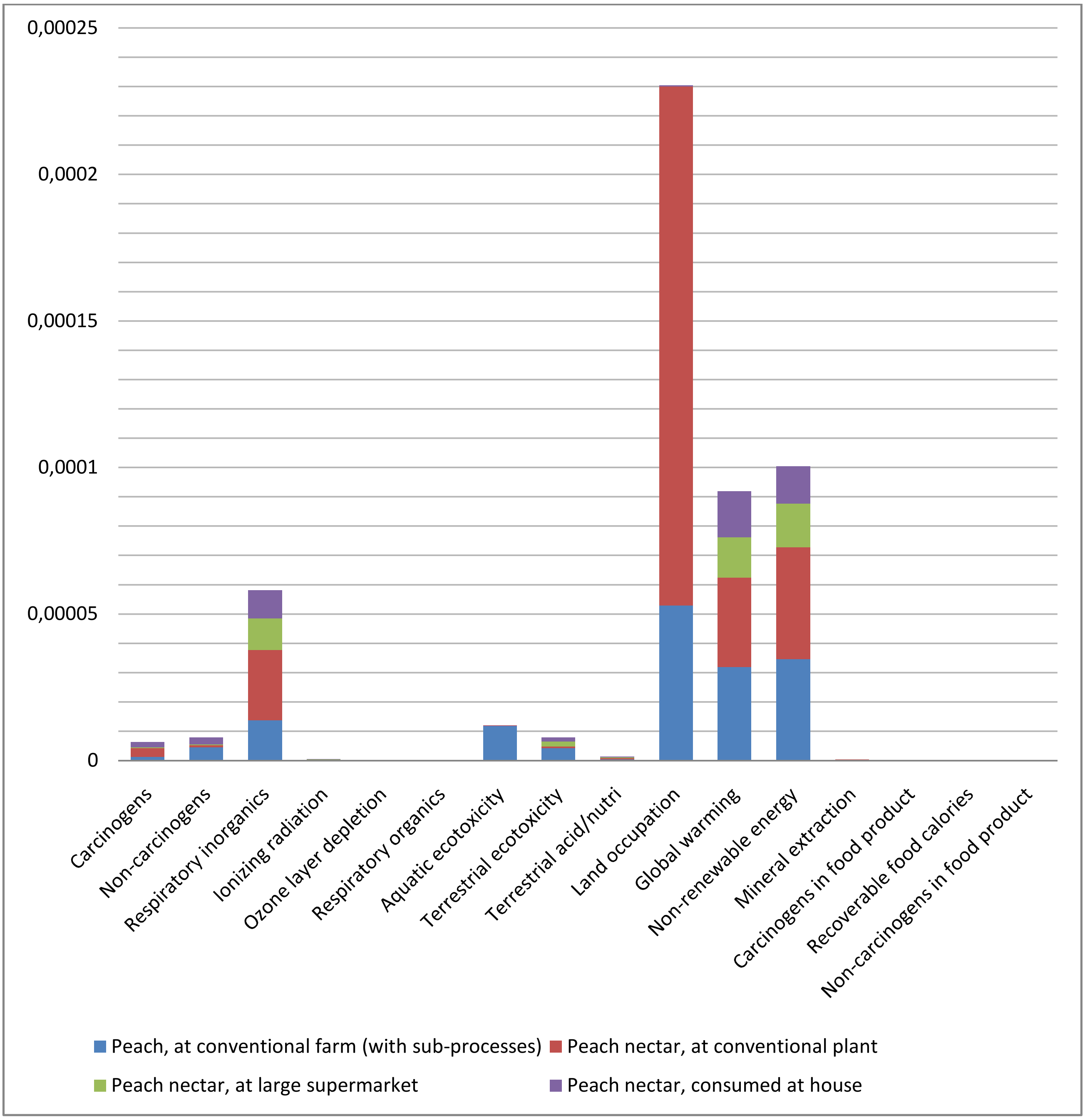
Tab. 4.9 The weighting per single score per impact category of the process Peach nectar, farm to fork

Damage category	Impact category	Unit	Total	Peach, at conventional farm	Peach nectar, at conventional plant	Peach nectar, at large supermarket	Peach nectar, consumed at house
Total	Total	Pt	0,000517	0,000155	0,000275	4,23E-05	4,41E-05
Human health	Carcinogens	Pt	6,25E-06	1,19E-06	3,05E-06	2,59E-07	1,75E-06
	Non-carcinogens	Pt	7,86E-06	4,46E-06	8,07E-07	2,91E-07	2,3E-06
	Respiratory inorganics	Pt	5,81E-05	1,37E-05	2,4E-05	1,08E-05	9,58E-06
	Ionizing radiation	Pt	4,03E-07	8,66E-08	1,83E-07	6,01E-08	7,31E-08
	Ozone layer depletion	Pt	7,72E-08	6,09E-09	6,66E-08	2,23E-09	2,29E-09
	Respiratory organics	Pt	1,15E-07	2,04E-08	4,65E-08	1,25E-08	3,57E-08
	Carcinogens in food p.	Pt	0	0	0	0	0
	Recov. food calories	Pt	7,6E-09	1,56E-09	7,82E-10	2,64E-09	2,61E-09
	Non-carcin. in food p.	Pt	2,17E-12	2,17E-12	0	0	0
Ecosystem quality	Aquatic ecotoxicity	Pt	1,19E-05	1,16E-05	2,56E-07	2,94E-08	2,55E-08
	Terrestrial ecotoxicity	Pt	7,81E-06	4,24E-06	4,34E-07	1,86E-06	1,27E-06
	Terrestrial acid/nutri	Pt	1,17E-06	3,85E-07	4,22E-07	1,92E-07	1,68E-07
	Land occupation	Pt	0,00023	5,29E-05	0,000177	9,17E-08	4,06E-07
Climate change	Global warming	Pt	9,19E-05	3,2E-05	3,04E-05	1,37E-05	1,57E-05
Resources	Non-renewable energy	Pt	0,0001	3,47E-05	3,81E-05	1,49E-05	1,28E-05

	Mineral extraction	Pt	2,75E-07	3,77E-08	1,96E-07	2,54E-08	1,58E-08

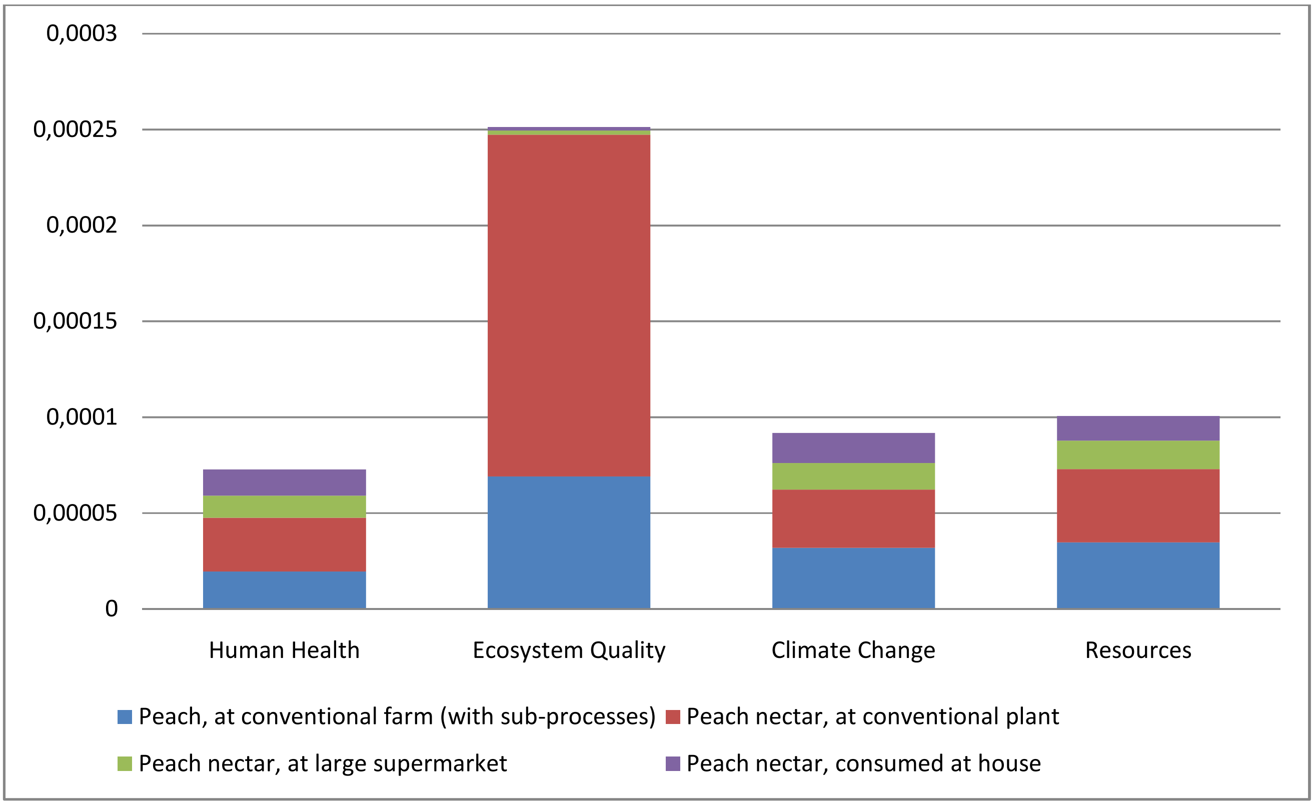
The total damage determined by the production, distribution and consumption of 1l of peach nectar is equal to 0.00051674 Pt. As already argued in the previous paragraphs, the nectar shows the worst environmental performance in **Land Occupation**, which is the most important impact category in terms of damage, with nearly half of the damage (0,00023Pt) attributable to it.

Fig. 4.6Diagram of Weighting per Impact Category of the process **Peach nectar, farm to fork**



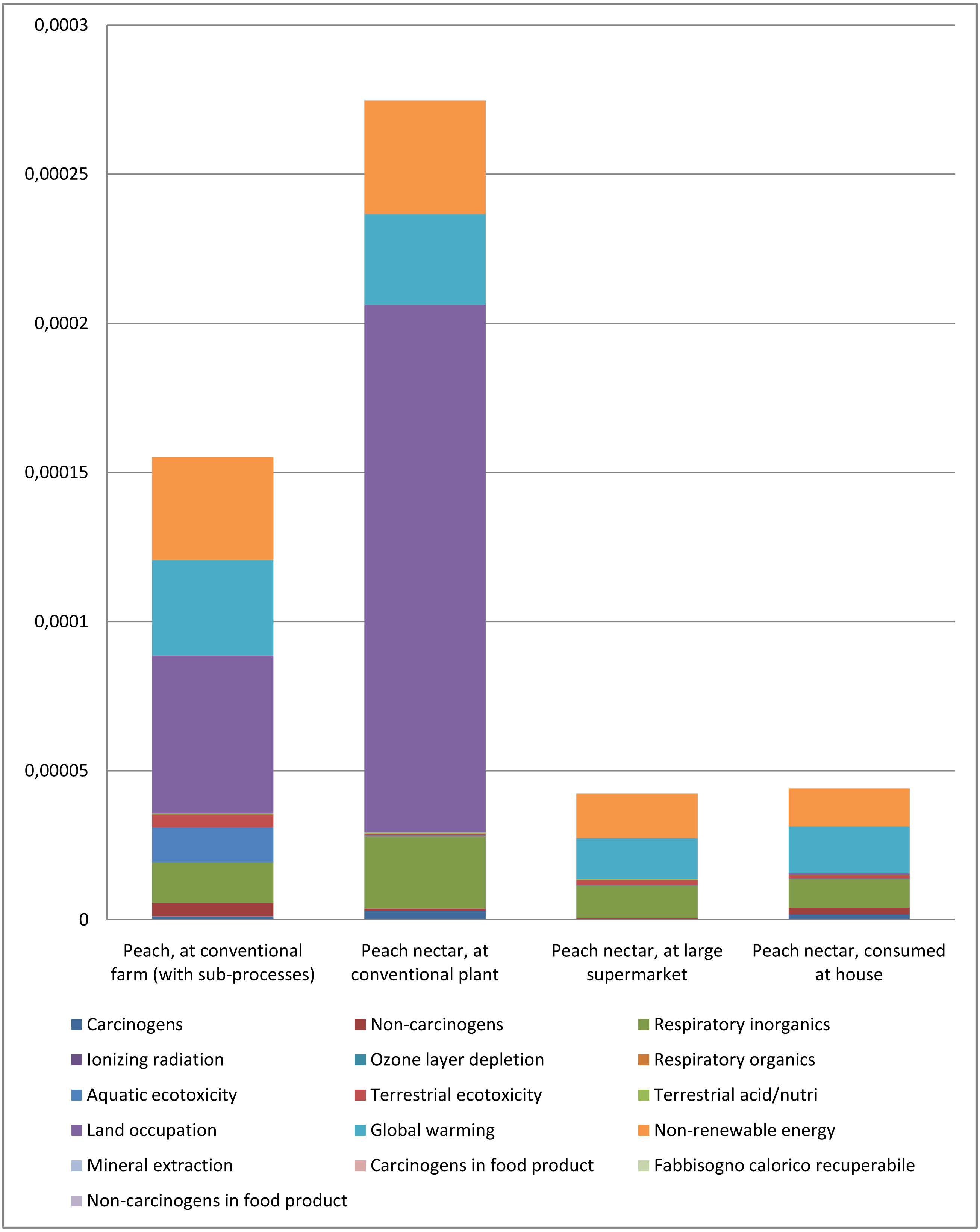
Nevertheless, also **Non-renewable energy** consumption (both direct and indirect) plays a relevant role, representing nearly one fifth of the single score (0,0001Pt), followed by the **Global warming** effects of the various emissions inventoried (9,19E-05Pt). Finally, another share of the score is imputable to **Respiratory inorganics**, which determine more than the 10% of the final damage (almost 0,00006 Pt). Fig. 4.6 shows the weighting per impact category and the relative contribution of the 4 segments of the nectar chain. In all the four major categories listed, nectar processing represents the more relevant segment, followed by cultivation. Given the relevance of land used, mainly for the production of added ingredients, also in the damage categories, the main impact derives from **Ecosystem Quality**. In Fig. 4.7 Diagram of Weighting per damage category of the process Peach nectar, farm to fork it is show the weithing per damage category of the peach nectar.

Fig. 4.7 Diagram of Weighting per damage category of the process Peach nectar, farm to fork



From the figure it is possible to argue that about half of the total impact caused by the nectar affects the ecosystem, while **Resources** and **Climate change** categories represent about the 37% of the damage. Thus, the category with the least impact is **Human Health** (14,09%).Focusing on the segments contribution, obviously, figures underline the preminence of nectar processing, compared to the others (Fig. 4.8).

Fig. 4.8Diagram of single score of the process <u>Peach nectar, farm to fork</u>



The process representing the transformation of peaches in nectar (Peach nectar, at conventional plant) determines 0,000275Pt of damage, which is the 53.21% of the total. Most of the damage is related to land use and energy consumption, including its consequences on greenhouse gas emissions. A 30.06% is due to the cultivation of peaches (Peach at conventional farm (with sub-processes) for a total of 0,000155 Pt. Also in this case, land occupation plays a major role in the composition of the damage, together with energy and global warming: the inclusion of a small shed in this process thus leads to a greater relevance of energy inputs and all the effects related, such as respiratory inorganics and CO2 emissions. Nevertheless, it must be also noted that this is the segment with the highest impact on terrestrial and acquaticecotoxicity, as well as the highest emission of non-carcinogens.

Finally, the other two segments, distribution and consumption, almost equally share the remaining 16,73% of the final score (8.19% due toPeach nectar, at large supermarket and 8.54% due toPeach nectar, consumed at house), largerly caused in both cases by the direct and indirect effects of energy consumption. Nevertheless there's a relevant difference, in the emission of carcinogens and non-carcinogens , which is higher in the case of household consumption.

4.3 Sensitivity analysis and interpretation

In order to evaluate the completeness and the consistency of the LCA conducted, a sensitivity analysis has been conducted. Given the main objective of the comparative study - the impacts of potential exploitation of biomasses for energy use - the main aim of this sensitivity analysis has been to compare the conventional peach nectar chain with an alternative hypothetical chain, in which the different flows of wastes are recovered through recycling. In the specific, it has been supposed the use of prunings for the production of Medium Density Fibreboard (MDF), the use of the other by-products (i.e. peelings, wasted puree, etc.) for composting, as well as the recycling of the different materials composing the packaging. In the following paragraphs, the inventory of the nectar chain with recycle and the results of comparison are presented.

4.3.1 Inventory of the chain with recycle processes

The nectar chain that includes the recycle of various waste flows has been represented with a single process (Peach nectar, farm to fork (with recycle), composed by the four sub-processes previously used. As showed by the following table (Tab. 4.10), in this process, the same functional unit has been used (3623,4l of peach nectar consumed).

Tab. 4.10 The process Peach nectar, farm to fork (with recycle)

Product/s	Amount	Unit	Notes/Functional unit (FU)
Peach nectar, farm to fork	3623,4	l	Net peach nectar volume consumed = 3660 briks of 1l x 0,99 (1% waste) = 3623,4 l.
Materials/fuels			
Peach, at conventional farm (with sub-processes and recycle)	2,6282	ton	Peach cultivated which are used in processing. Peach produced in 19yy life of orchard = 240 ton
Peach nectar, at conventional plant (only compost)	3697	p	Peach nectar briks produced and sold to the distributer. Nectar produced out of 2.6282 tons of peaches.
Peach nectar, at large supermarket (with recycle)	3660	p	Peach nectar distributed and sold. Net peach nectar sold = 3697briks of 1l x 0.99 (1% waste) = 3660 p.
Peach nectar, consumed at house (with recycle)	3623,4	l	Peach nectar bought and consumed. Nectar consumed = 1 brik of 1l bought x 0.99 (1% waste) = 0.99 l.

Nevertheless, within the single segments, the following modifications have been included. In the cultivation process (Peach, at conventional farm (with sub-processes and recycle)), it has been included, among the inputs, the process representing the recycle of prunings into MDF(Wood recycle (from Medium density fibreboard, at plant/RER U)) (Tab. 4.11).

Tab. 4.11 The process Peach, at conventional farm (with sub-processes and recycle)

Products	Quantity	Unit	Comment/Notes
Peach, at conventional farm (with sub-processes and recycle)	240	ton	*Functional unit*: peach production over 19 years of orchard lifetime, calculated basing on (Cerutti et al. 2010): - 0 tons from year 0 to year 3 (year 0 is the nursery) - Increasing from year 4 to year 5 = 8t/ha*a

			- Constant from 6 to 18: 16t/ha - Decreasing from year 19: 8t/ha*a = Year 19
Resources			
Occupation, permanent crop, fruit	19	ha*a	Orchard lifetime: 19yy per 1 ha
Transformation, from pasture and meadow, intensive	0,29	ha	Original land use as pasture: 29%
Transformation, from arable, non-irrigated	0,71	ha	Original land use as not irrigate arable land: 71%
Transformation, to permanent crop, fruit	1	ha	Total land use: 1ha
Energy, gross calorific value, in biomass	284127,3	MJ	Total wood produced over the lifetime, calculated as: - Average trunk height: 0.60m with a section area of 0.0102m2 (Branzanti & Ricci 2001, p. 168); 3 main branches (lenght: 1.5m and section area: 0,0051m2); a further 10% of small branches, of which the 50% is cut each year; Wood density with 70% wet content: 900kg/m3; Roots, assumed to be the 25% of the total weight (Branzanti & Ricci 2001, p. 2) Total number of trees/ha (Fideghelli & Sansavini (eds.) 2005, p. 119): - Distance between the row: 5m - Distance between the threes: 3m - Number of threes: 666.66 Higher heating value: 7.2MJ/kg
Carbon dioxide, in air	21704,17	kg	Total CO2 uptake, calculated as function of carbon content in the wood: - Fresh wood weight: 39462kg - Dry wood weight: 39462*0.3 - Carbon content: 0.5kg/kg
Wood, hard, standing	43,84681	m3	Total wood volume
Peach wasted	4,8	ton	A 2% waste of uncollected peaches is assumed. In this process, this amount is simply reported as food waste and it is assumed to be left on the soil.
Materials/fuels			
Peach tree, at nursery	666,66	p	In this process, it is accounted all the damage related to the nursery process.
Electricity/heat			
Sub-process Fertilization	240	ton	This process includes only the various inputs
Sub-process Agro-processing	240	ton	This process includes only the various inputs
Sub-process Pesticides	240	ton	This process includes only the various inputs
Electricity, low voltage, at grid/IT U	6935	kWh	Electricity consumption: 1 kWh per day per year is assumed, to account for the energy consumption of a shed
Heat, natural gas, at boiler condensing modulating >100kW/RER U	1058832	MJ	Heat consumption, calculate assuming a shed (3*4*3m) heated for 2h/d for 3 months/yy
Wood recycle (from Medium density fibreboard, at plant/RER U)	43,84681	m3	Recycle of the prunings and the end of life of the orchard

Social issues			
Recoverable food calories	1296000	kcal	Food calories waste with a 2% uncollected peach

In the processing (Peach nectar, at conventional plant (only compost)), all the organic waste is managed as feedstock for the production of compost, which is represented by the process Composting organic waste/RER U (da Composting NL 1995 (sub) di IVAMLCA3); thus, animal feed is not considered anymore (Tab. 4.12).

Tab. 4.12 The process Peach nectar, at conventional plant (with recycle)

Products	Quantity	Unit	Functional unit/Notes
Peach nectar, at conventional plant (with recycle)	3697	p	Functional unit: production of 3697 briks of 1l of nectar, for which 2,6282t of peaches have been used. The production of nectar implies the generation of 4 amounts of waste, which are considered for the end of life treatment.
Electricity/heat			
Peachwashing	2,628234	ton	FU calculated on the hypothesis that the selection implies a 2% waste referred to the amount of peaches that go into the stoning machine.
Peach selection	2,5767	ton	FU of the process calculate on the base of whole peaches weight.
Peach stoning	2,422098	ton	FU constituted by the weight of half peaches
Stoned peach selection	2,373658	ton	FU constituted by the weight of half peaches
Peach puree extraction	2,278752	ton	The FU is equal to the quantity of puree that can be extracted from the stoned peaches
Puree de-airing	2,2788	ton	FU: amount of puree de-aired
Pasteurization	2,2788	ton	FU: amount of pastorized puree
Acqueous solution mixing	1,848475	ton	FU: amount of acqueous solution mixed
Peach nectar mixing	4,1273	ton	FU: amount of puree and acqueousslution mixed
Puree de-airing	4,1273	ton	FU: amount of nectar de-aired
Peach nectar homogenization	3,696972	m3	FU: volume of nectar homogenizated (density equal to 1,1164 t/m3)

Pasteurization	4,1273	ton	FU: amount of nectar pastorized
Aseptic filling	3696,972	p	FU: number of 1l briks packaged
Social issues			
Recoverable food calories	7099,032	kcal	Amount of calories wasted in the peaches selection
Waste to treatment			
Compostingorganicwaste/RER U (da Composting NL 1995 (sub) di IVAMLCA3)	0,35058	ton	Treatment of residues: composting.

In the distribution process (Peach nectar, at large supermarket (with recycle)), the management of wasted nectar is not represented by municipal wastewater treatment, but is supposed to be composted (same process as in the previous segment). Likewise, packaging is not treated with incineration but its three basic materials are recycled (see the processes Recycling PE/RER U (withelettricity), Recycling aluminium/RER U (with scrap), andRecycling cardboard/RER U (with waste collection) (Tab. 4.13).

Tab. 4.13 The process Peach nectar, at large supermarket (with recycle)

Products	Amount	Unit	Functional unit/Notes
Peach nectar, at large supermarket	3660,03	p	FU: amount of nectar sold. It is assumed a 1% of unsold nectar which is treated as waste
Resources			
Peach nectar wasted	41,27331	kg	This input represent the amoun of unsold nectar, which is assumed to be the 1% basing on the average food waste in the distribution (between the 0,7 andthe 1,2 % of the sector income
Electricity/heat			
Transport, lorry 20-28t, fleet average/CH U	412733,1	kgkm	Transport of the nectar for 100 km from the processing plant
Retail (long time stor., room temp., large store) (IT)	4127,331	kg	It represent the electricity and heat needed for a 1kg of goods distributed
Social issues			
Recoverable food calories	23938,52	kcal	Food wasted in the distribution. The amount of calories has been

			estimated basing on the the value of 58 kcal per 100g of nectar(Valfrutta n.d.)
Waste to treatment			
Recycling PE/RER U (con elettricità)	0,503487	kg	Recycle of the plastic part of the packaging with the inclusion of electricity consumption for collection.
Recycling aluminium/RER U (con scrap)	0,119634	kg	Recycle of the aluminium part of the packaging with the inclusion of electricity consumption for collection.
Recyclingcardboard/RER U (con raccolta rifiuto)	1,771115	kg	Recycle of the carboard part of the packaging with the inclusion of electricity consumption for collection.
Compostingorganicwaste/RER U (da Composting NL 1995 (sub) di IVAMLCA3)	41,273308	kg	End of life of the unsold nectar is assumed to be the sewage water

Finally, in the consumption process (Peach nectar, consumed at house (with recycle)), the same modification have been made for the representation of the wasted nectar and the packaging treatment (Tab. 4.14).

Tab. 4.14 The process Peach nectar, consumed at house (with recycle)

Products			
Peach nectar, consumed at house	0,99	l	FU: consumption of 1 brick of nectar per a total volume of 0,99l, including a 1% waste
Resources			
Peach nectar wasted	0,011164	kg	A 1% wasteisassumed
Electricity/heat			
Transport, passenger car/RER U	0,6	personkm	It is assumed a weekly purchase of 50 €, which includes a brik of 1,50€; transport is then economically allocated:1p*10km*2trips*1,5/50
Refrigerator, small, A (IT)	3	l*day	Fridge use: 3dd (expiry date after opening)
Social issues			
Recoverable food calories	6,47512	kcal	Food kcal calculated as in the distribution segment, considering a 1% waste
Waste to treatment			

Recycling PE/RER U (con elettricità)	0,013618797	kg	Calculated as in the distribution segment
Recycling aluminium/RER U (con scrap)	0,003235971	kg	-
Recyclingcardboard/RER U (con raccolta rifiuto)	0,047906829	kg	-
Compostingorganicwaste/RER U (da Composting NL 1995 (sub) di IVAMLCA3)	0,011164	kg	-

4.3.2 Analysis of the comparison between the 2 scenarios

The comparison between the conventional peach nectar chain and the chian with recycle of waste has been conducted using the same analysis method than the previous impact assessment. In the specific, the main differences in terms of single score weighting have been reported, and evaluated through the specification of scores per substances and processes. As shown in Tab. 4.15, the process that foresees the recycle of organic waste and packaging generates an 3% higher impact than the conventional chain.

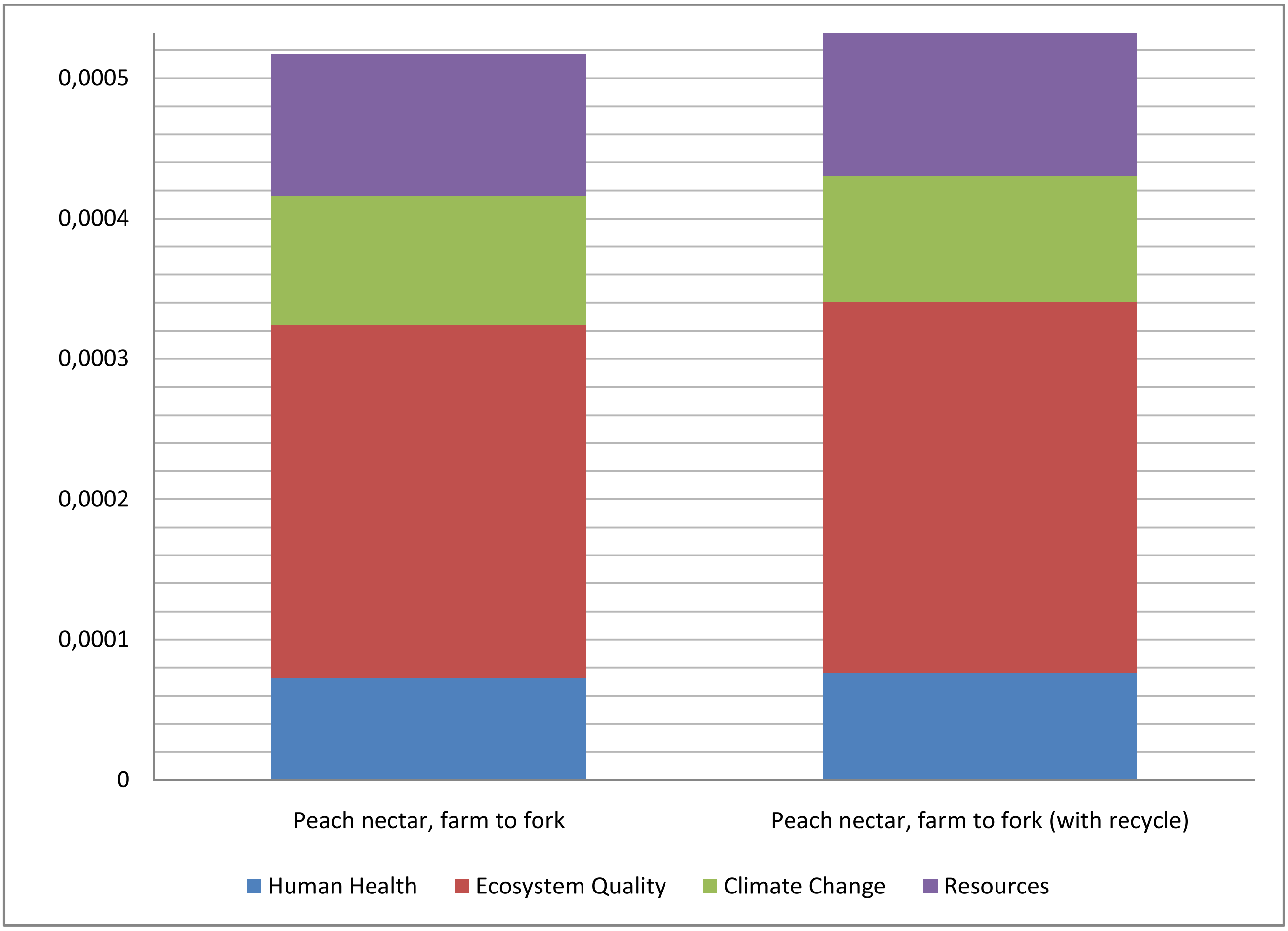
Tab. 4.15weighting per single score with IMPACT of the comparison between the processes Peach nectar, farm to forkand Peach nectar, farm to fork (with recycle)and percentage variation per impact category

Damage category	Impact category	A) Peach nectar, farm to fork	B) Peach nectar, farm to fork (with recycle)	Δ (B-A) in %
Total	Total	0,000516741	0,000532272	3,005736
Human health	Carcinogens	6,24841E-06	6,19447E-06	-0,86323
	Non-carcinogens	7,85856E-06	9,54621E-06	21,47534
	Respiratory inorganics	5,80982E-05	5,95272E-05	2,459587
	Ionizing radiation	4,02697E-07	4,11041E-07	2,072115
	Ozone layer depletion	7,71872E-08	7,73295E-08	0,184338
	Respiratory organics	1,15139E-07	1,15763E-07	0,54145

	Carcinogens in food p.	0	0	-
	Recov. food calories	7,59553E-09	7,59553E-09	0
	Non-carcin. in food p.	2,17236E-12	2,17236E-12	0
Ecosystem quality	Aquatic ecotoxicity	1,19485E-05	1,20151E-05	0,557747
	Terrestrial ecotoxicity	7,80563E-06	2,15823E-05	176,4962
	Terrestrial acid/nutri	1,16758E-06	1,2159E-06	4,138393
	Land occupation	0,000230428	0,000230442	0,005919
Climate change	Global warming	3,2E-05	3,04E-05	-2,86314
Resources	Non-renewable energy	3,47E-05	3,81E-05	1,177139
	Mineral extraction	3,77E-08	1,96E-07	0,76018

Most of this difference can be attributed to the impact category **Terrestrial ecotoxicity**, which registers a 176,5% increase, mainly due to the higher emissions of heavy metals in the production of compost. In the specific, it is caused by the larger amount of organic waste treated with this process, which determines the release of *Zinc* in soil. Likewise, in the category**Non-carcinogens**, the total damage for the chain with recycle is 21,48% higher, especially becuase of the emission of *Arsenic* in soil, resulting from the composting process. Finally, the third relevant difference can be noticed in the impact of **Non-renewable energy**, where the total score registers a 1,18% growth, as the consumption of energy is higher in some of the recycling processes included, than in conventional end-of-life treatments. The only relevant reduction of the damage can be registered in the category **Global warming**, with about a 3% decrease of the total score. As result of these differences, the damage categories present similar variations, with a marked increase in Ecosystem quality and Resources, a minimal growth in Human health, and a slight decrease in Climate change (see Fig. 4.9).

Fig. 4.9Diagram of the weighting per single score with IMPACT of the comparison between the processes <u>Peach nectar, farm to fork</u>and <u>Peach nectar, farm to fork (with recycle)</u>



This comparison underlines how the results of the analysis of the conventional chain are sensitive to the end-of-life scenarios of the various waste flows. The main reason for this sensitiveness is in the lack of data on the impact of prunings, which seems to lead to an incomplete analysis of the **Ecosystem Quality** damage. In the specific, the inability to account for the organic matter content and effect of prunings on soil probably led to anoverestimation of the **Ecosystem Quality** damage in the conventional chain, compared to the recycle scenario. On the contrary, the lack of data on the heavy metals in the plant biomass probably caused an underestimation of their negative effects on soil in the conventional chain, considering that the method chosen, IMPACT2002+, considers all these inputs as resulting in a damage. Thus, it is difficult to understand completely how the **Ecosystem Quality** category could be modified in a more detailed analysis of these aspects, which are to some extent relevant also in the comparison with the energy recovery scenario.Nevertheless, in must be noted that this sensitiveness is actually related to an impact category (**Terrestrial ecotoxicity**), with a relatively small influence, compared to **Land occupation**.

4.4 Mainresults and discussion

From the analysis carried out, it is possible to argue that the peach nectar is a product with a relevant environmental impact. As observed in the previous paragraphs, most of the impact along the farm-to-fork chain is observed in the processing phase, mainly because of the use of added ingredients such as sugar and glucose. In fact, the cultivation of the respective feedstock (sugar beet and maize) causes a relatively high direct and indirect (green manure) land use. Therefore, the use of more sustainable ingredients or production practices could represent a sound reduction strategy. Nevertheless, also the consumption of energetic resources, in both the cultivation and transformation phases, represents a relevant factor in the final damage, given the subsequent effect in terms of climate change emissions. As far as food waste is regarded, besides the general lower efficiency, the amount of food calories wasted amounts at around 20 kcal per liter of nectar, with an higher influence of processed nectar wasted. Finally, the results proved sensitive to the lack of data on the impact of prunings on soil organic matter and heavy metals content. This aspect must be thus taken into account when analyzing the potential impact of removing biomass for energetic purposes. In the next chapter, the conventional chain will be compared to the scenario of self-production and consumption of bioenergy from wastes.

5 Comparative analysis between conventional and integrated peach nectar chains

This chapter presents and discusses the results of a comparative LCA between the conventional peach nectar chain analysed before and an hypothetical scenario where waste, losses and byproducts identified are used to produce bioenergy, through cogeneration technologies,to be consumed in the system. As already mentioned in the chapter 3, a similar chain, with bioenergy self-production and consumption, can be analysed in the LCA, using two different methodologies, with diverse assumptions and results: the “avoided product” approach and the “co-product” approach. Both of them have been used in the present study, in order to derive crucial methological results, such as advantages and misrepresentations. Thus, the comparison between the conventional and the integrated scenario is actually a comparison between three different processes:

- The process representing the conventional scenario:Peach nectar, farm to fork (chap. 4);
- The process representing the second scenario, with the avoided “energies”: Peach nectar, integrated bioenergy, farm to fork (avoided prod.)(par. 5.1);
- The process representing the second scenario, with the coproduced “energies”: Peach nectar, integrated bioenergy, farm to fork (coproduct.)(par. 5.2).

In the following paragraphs, the LCI, as well as the single score assessment, of both the new processes are presented, with a description of modifications, assumptions, and differences. Then, a paragraph reports the results of the complete LCIA, with a comparative approach to the analysis of characterization, damage assessment, normalization and weighting, according to the IMPACT method and to the LCA-related ISO standards (ISO 2006a; ISO 2006b).A final paragraphis aimed at discussing the main results of the LCA, with a specific focus on fossil energy consumption reduction and the effect of the reuse of residues and food waste.

5.1 The integrated bioenergy chain with avoided energies

5.1.1 Inventory analysis

In this paragraph it is described the scenario with integrated bioenergy represented through the avoided products approach. For this process, the conventional chain has been modified including in each segment the electricity and heat cogenerated from waste and residues, in the form of avoided products. The process representing the whole chain is presented in Tab. 5.1.

Tab. 5.1 The process Peach nectar, integrated bioenergy, farm to fork (farm to fork)

Product/s	Amount	Unit	Notes/Functional unit (FU)
Peach nectar, integrated bioenergy, farm to fork (avoided prod.)	3623,4	l	Net peach nectar volume consumed = 3660 briks of 1l x 0,99 (1% waste) = 3623,4 l.
Materials/fuels			
Peach, at integrated bioenergy farm (with sub-processes - avoided prod.)	2,6282	ton	Peach cultivated which are used in processing. Peach produced in 19yy life of orchard = 240 ton
Peach nectar, at integrated bioenergy plant (avoided prod.)	3697	p	Peach nectar briks produced and sold to the distributer. Nectar produced out of 2.6282 tons of peaches.
Peach nectar, at integrated bioenergy supermarket (avoided prod.)	3660	p	Peach nectar distributed and sold. Net peach nectar sold = 3697briks of 1l x 0.99 (1% waste) = 3660 p.
Peach nectar, consumed at integrated bioenergy house (avoided prod.)	3623,4	l	Peach nectar bought and consumed. Nectar consumed = 1 brik of 1l bought x 0.99 (1% waste) = 0.99 l.

Within the single segments, the following modifications have been included. In the cultivation process (Peach, at integrated bioenergy farm (with sub-processes - avoided prod.)), both electricity and heat produced from waste have been included as avoided products, in order to substitute for fossil fuel consumption, and as input, to represent the damage deriving from prunings co-combustion (Tab. 5.2).

Tab. 5.2 The process Peach, atintegrated bioenergy farm (with sub-processes - avoided prod.)

Products	Quantity	Unit	Comment/Notes
Peach, at integrated bioenergy farm (with sub-processes - avoided prod.)	240	ton	*Functional unit*: peach production over 19 years of orchard lifetime, calculated basing on (Cerutti et al. 2010): - 0 tons from year 0 to year 3 (year 0 is the nursery) - Increasing from year 4 to year 5 = 8t/ha*a - Constant from 6 to 18: 16t/ha - Decreasing from year 19: 8t/ha*a = Year 19
Avoided products			
Industrial residue wood, mix, hardwood, u=40%, at plant/RER U	25,436	m3	Total amount of wood deriving from the end of life of the orchard, represented as avoided product, in order to nullify the needed wood to produce bioenergy
Industrial residue wood, mix, hardwood, u=40%, at plant/RER U	18,41082	m3	Total amount of wood deriving from the prunings, represented as avoided product, in order to nullify the needed wood to produce bioenergy
Electricity, low voltage, at grid/IT U	3748,348	kWh	Total amount of electricity produced from prunings, and represented as avoided consumption of electricity from network
Heat, natural gas, at boiler condensing modulating >100kW/RER U	355390,5	MJ	Total amount of heat produced from prunings, and represented as avoided consumption of heat from natural gas
Resources			

Occupation, permanent crop, fruit	19	ha*a	Orchard lifetime: 19yy per 1 ha
Transformation, from pasture and meadow, intensive	0,29	ha	Original land use as pasture: 29%
Transformation, from arable, non-irrigated	0,71	ha	Original land use as not irrigate arable land: 71%
Transformation, to permanent crop, fruit	1	ha	Total land use: 1ha
Energy, gross calorific value, in biomass	284127,3	MJ	Total wood produced over the lifetime, calculated as: - Average trunk height: 0.60m with a section area of 0.0102m2 (Branzanti & Ricci 2001, p. 168); 3 main branches (lenght: 1.5m and section area: 0,0051m2); a further 10% of small branches, of which the 50% is cut each year; Wood density with 70% wet content: 900kg/m3; Roots, assumed to be the 25% of the total weight (Branzanti & Ricci 2001, p. 2) Total number of trees/ha (Fideghelli & Sansavini (eds.) 2005, p. 119): - Distance between the row: 5m - Distance between the threes: 3m - Number of threes: 666.66 Higher heating value: 7.2MJ/kg
Carbon dioxide, in air	21704,17	kg	Total CO2 uptake, calculated as function of carbon content in the wood: - Fresh wood weight: 39462kg - Dry wood weight: 39462*0.3 - Carbon content: 0.5kg/kg
Wood, hard, standing	43,84681	m3	Total wood volume
Peach wasted	4,8	ton	A 2% waste of uncollected peaches is assumed. In this process, this amount is simply reported as food waste and it is assumed to be left on the soil.
Materials/fuels			
Peach tree, at nursery	666,66	p	In this process, it is accounted all the damage related to the nursery process.
Electricity/heat			
Sub-process_Fertilization	240	ton	This process includes only the various inputs
Sub-process_Agro-processing	240	ton	This process includes only the various inputs
Sub-process_Pesticides	240	ton	This process includes only the various inputs
Electricity, low voltage, at grid/IT U	6935	kWh	Electricity consumption: 1 kWh per day per year is assumed, to account for the energy consumption of a shed
Heat, natural gas, at boiler condensing modulating >100kW/RER U	1058832	MJ	Heat consumption, calculate assuming a shed (3*4*3m) heated for 2h/d for 3 months/yy
Electricity, at cogen ORC 1400kWth, wood, emission control, allocation exergy/CH U (hardwood/mobile chopper)	3748,348	kWh	The amount of electricity produced is proportional to the volume of chips that can be produced from the orchard wood and to the amount of chips needed to produced 1 kWhof electricity as allocated in the original multioutput process. In the specific, total heat is equal to: (18,411+25,436)/0,329*0,161/0,0057244
Heat, at cogen ORC	355390,5	MJ	The amount of heat produced is proportional to the volume of chips that

1400kWth, wood, emission control, allocation exergy/CHU(hardwood/mobile chopper)			can be produced from the orchard wood, to the amount of chips needed to produced 1 MJ of heat as allocated in the original multioutput process. In the specific, total heat is equal to: (18,411+25,436)/0,329*0,839/0,00031463
Social issues			
Recoverable food calories	1296000	kcal	Food calories waste with a 2% uncollected peach

In a similar way, in the processing (Peach nectar, at integrated bioenergy plant (avoided prod.)), all the organic waste is managed as feedstock for the anaerobic digestion and the cogeneration of electricity and heat from biogas (Tab. 5.3).

Tab. 5.3 The process Peach nectar, at integrated bioenergy plant (avoided prod.)

Products	**Quantity**	**Unit**	**Functional unit/Notes**
Peach nectar, at integrated bioenergy plant (avoided prod.)	3697	p	Functional unit: production of 3697 briks of 1l of nectar, for which 2,6282t of peaches have been used. The production of nectar implies the generation of 4 amounts of waste, which are considered for the end of life treatment.
Avoided products			
Electricity, medium voltage, at grid/IT U	748,80	kWh	Total amount of electricityavoided through the cogeneration from biogas from peach processing waste
Heat, natural gas, at industrial furnace >100kW/RER U	4648,98	MJ	Total amount of heatavoided through the cogeneration from biogas from peach processing waste
Electricity/heat			
Peachwashing	2,628234	ton	FU calculated on the hypothesis that the selection implies a 2% waste referred to the amount of peaches that go into the stoning machine.
Peach selection	2,5767	ton	FU of the process calculate on the base of whole peaches weight.
Peach stoning	2,422098	ton	FU constituted by the weight of half peaches
Stoned peach selection	2,373658	ton	FU constituted by the weight of half peaches
Peach puree extraction	2,278752	ton	The FU is equal to the quantity of puree that can be extracted from the stoned peaches
Puree de-airing	2,2788	ton	FU: amount of puree de-aired
Pasteurization	2,2788	ton	FU: amount of pastorized puree

Acqueous solution mixing	1,848475	ton	FU: amount of acqueous solution mixed
Peach nectar mixing	4,1273	ton	FU: amount of puree and acqueousslution mixed
Puree de-airing	4,1273	ton	FU: amount of nectar de-aired
Peach nectar homogenization	3,696972	m3	FU: volume of nectar homogenizated (density equal to 1,1164 t/m3)
Pasteurization	4,1273	ton	FU: amount of nectar pastorized
Aseptic filling	3696,972	p	FU: number of 1l briks packaged
Electricity, at cogen with biogas engine, agricultural covered, alloc. exergy/CH U (biogas da biowaste)	748,80	kWh	FU: total electricity produced through the cogeneration from biogas from peach processing waste, calculated as follows: - Amount of waste = 0.35058t - Biogas yield (from Biogas, from biowaste, at agricultural co-fermentation, covered/CH U) = 1m3/kg of fresh biowaste - Amount of biogas: 0.35058E3m3 - Allocation (Jungbluth et al. 2007): 0.861 - Biogas allocated on electricity: 301.85m3 - Amount of biogas needed to produce 1 kWh: 0,40311m3/kWh (Electricity, at cogen with biogas engine, agricultural covered, alloc. Exergy) - Total: 301.85m3/0,40311m3/kWh=748.8kWh
Heat, at cogen with biogas engine, agricultural covered, allocation exergy/CH U (biogas da biowaste)	4648,98	MJ	FU: total heat produced through the cogeneration from biogas from peach processing waste, calculated as follows: - Amount of waste = 0.35058t - Biogas yield (from Biogas, from biowaste, at agricultural co-fermentation, covered/CH U) = 1m3/kg of fresh biowaste - Amount of biogas: 0.35058E3m3 - Allocation (Jungbluth et al. 2007): 0.139 - Amount of biogas needed to produce 1 MJ: 0,010482 m3/MJ (Heat, at cogen with biogas engine, agricultural covered, alloc. Exergy) - Total: 350.58*0.139/0,010482 m3/MJ=4648,98MJ
Social issues			
Recoverable food calories	7099,032	kcal	Amount of calories wasted in the peach selection

In the distribution process (Peach nectar, at integrated bioenergy supermarket (avoided prod.)), unsold and wasted nectar has been assumed to be used as feedstock for the cogeneration of electricity and heat from biogas. Thus, both in the avoided products and in the inputs, it has been included the potential amount of energy that can be produced, using the same processes as in the processing segment (Tab. 5.4 The process).

Tab. 5.4 The process Peach nectar, at integrated bioenergy supermarket (avoided prod.)

Products	Amount	Unit	Functional unit/Notes
Peach nectar, at integrated bioenergy supermarket (avoided prod.)	3660,03	p	FU: amount of nectar sold. It is assumed a 1% of unsold nectar which is treated as waste
Avoided products			
Electricity, medium voltage, at grid/IT U	88,156	kWh	Total amount of electricityavoided through the cogeneration from biogas from peach nectar wasted
Heat, natural gas, at industrial furnace >100kW/RER U	547,32	MJ	Total amount of heatavoided through the cogeneration from biogas from peach nectar wasted
Resources			
Peach nectar wasted	41,27331	kg	This input represent the amoun of unsold nectar, which is assumed to be the 1% basing on the average food waste in the distribution (between the 0,7 andthe 1,2 % of the sector income
Electricity/heat			
Transport, lorry 20-28t, fleet average/CH U	412733,1	kgkm	Transport of the nectar for 100 km from the processing plant
Retail (long time stor., room temp., large store) (IT)	4127,331	kg	It represent the electricity and heat needed for a 1kg of goods distributed
Electricity, at cogen with biogas engine, agricultural covered, alloc. exergy/CH U (biogas da biowaste)	88,156	kWh	FU: total electricity produced through the cogeneration from biogas from peach nectar wasted, calculated as in the processing segment but considering as feedstock the 41,27331 kg of unsold nectar
Heat, at cogen with biogas engine, agricultural covered,	547,32	MJ	FU: total heat produced through the cogeneration from biogas from peach nectar waste, calculated as in the processing segment but considering as feedstock the 41,27331 kg of unsold nectar

allocation exergy/CH U (biogas da biowaste)			
Social issues			
Recoverable food calories	23938,52	kcal	Food wasted in the distribution. The amount of calories has been estimated basing on the the value of 58 kcal per 100g of nectar(Valfrutta n.d.)
Waste to treatment			
Recycling PE/RER U (con elettricità)	0,503487	kg	Recycle of the plastic part of the packaging with the inclusion of electricity consumption for collection.
Recycling aluminium/RER U (con scrap)	0,119634	kg	Recycle of the aluminium part of the packaging with the inclusion of electricity consumption for collection.
Recyclingcardboard/RER U (con raccolta rifiuto)	1,771115	kg	Recycle of the carboard part of the packaging with the inclusion of electricity consumption for collection.

Likewise, in the consumption process (Peach nectar, consumed at integrated bioenergy house (avoided prod.)), it has been included the cogeneration of electricity and heat from biogas obtained through the anaerobic digestion of wasted nectar (Tab. 5.5).

Tab. 5.5 The process Peach nectar, consumed at integrated bioenergy house (avoided prod.)

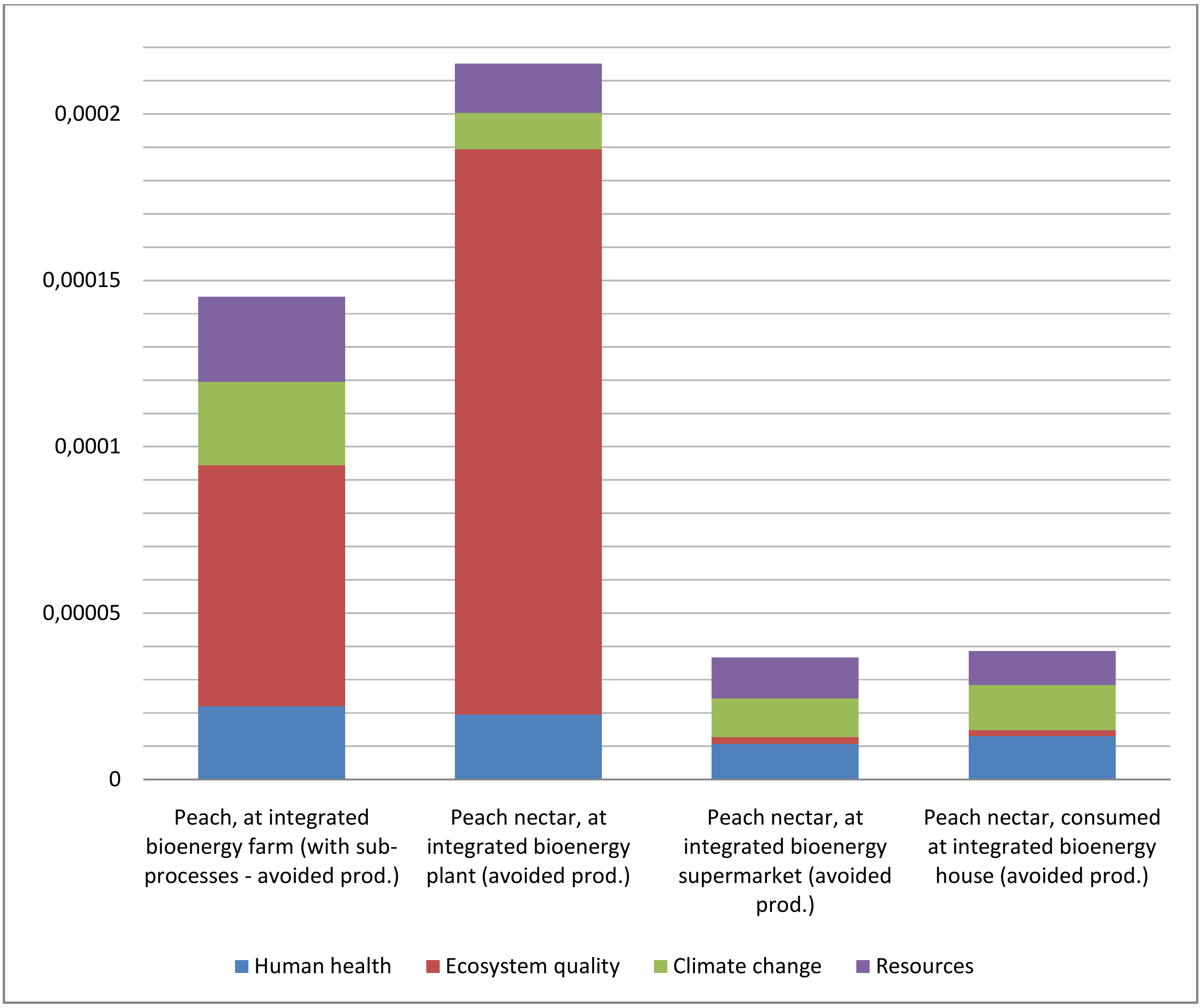
Products			
Peach nectar, consumed at integrated bioenergy house (avoided prod.)	0,99	l	FU: consumption of 1 brick of nectar per a total volume of 0,99l, including a 1% waste
Avoided products			
Electricity, medium voltage, at grid/IT U	0,023845114	kWh	Total amount of electricityavoided through the cogeneration from biogas from peach nectar wasted
Heat, natural gas, at industrial furnace >100kW/RER U	0,148043885	MJ	Total amount of heatavoided through the cogeneration from biogas from peach nectar wasted
Resources			
Peach nectar wasted	0,011164	kg	A 1% wasteisassumed

Electricity/heat			
Transport, passenger car/RER U	0,6	personkm	It is assumed a weekly purchase of 50 €, which includes a brik of 1,50€; transport is then economically allocated:1p*10km*2trips*1,5/50
Refrigerator, small, A (IT)	3	l*day	Fridge use: 3dd (expiry date after opening)
Electricity, at cogen with biogas engine, agricultural covered, alloc. exergy/CH U (biogas da biowaste)	0,023845114	kWh	FU: total electricity produced through the cogeneration from biogas from peach nectar wasted, calculated as in the processing segment but considering as feedstock the 0,011164 kg of unsold nectar
Heat, at cogen with biogas engine, agricultural covered, allocation exergy/CH U (biogas da biowaste)	0,148043885	MJ	FU: total heat produced through the cogeneration from biogas from peach nectar wasted, calculated as in the processing segment but considering as feedstock the 0,011164 kg of unsold nectar
Social issues			
Recoverable food calories	6,47512	kcal	Food kcal calculated as in the distribution segment, considering a 1% waste
Waste to treatment			
Recycling PE/RER U (con elettricità)	0,013618797	kg	Calculated as in the distribution segment
Recycling aluminium/RER U (con scrap)	0,003235971	kg	-
Recyclingcardboard/RER U (con raccolta rifiuto)	0,047906829	kg	-

5.1.2 Analysisof the integrated bioenergy chain with avoided energies

In this paragraph, the main results of the weighting per single score of the process Peach nectar, integrated bioenergy, farm to fork (avoided prod.) are presented. In Fig. 5.1 it is reported the diagram per damage category and segment. It is possible to note how avoided energies reduce quite sensitively the contribution of the **Non renewable energy** and **Climate change** categories in all the segments.

Fig. 5.1Diagram of the weighting per single score of the processPeach nectar, integrated bioenergy, farm to fork (avoided prod.)



More detailed data are listed in Tab. 5.6, where results per each impact category are presented. In par. 5.3 a complete LCIA of this process in comparison with the conventional chain is reported.

Tab. 5.6The weighting of the process Peach nectar, integrated bioenergy, farm to fork (avoided prod.)

Damage category	Impact category	Unit	Total	Peach, at integrated bioenergy farm (with sub-	Peach nectar, at integrated bioenergy plant (avoided	Peach nectar, at integrated bioenergy supermarket (avoided	Peach nectar, consumed at integrated bioenergy

				processes - avoided prod.)	prod.)	prod.)	house (avoided prod.)
Total	Total	Pt	0,000435	0,000145	0,000215	3,67E-05	3,85E-05
Human health	Carcinogens	Pt	5,38E-06	1,01E-06	2,45E-06	2,08E-07	1,7E-06
	Non-carcinogens	Pt	6,6E-06	5,25E-06	-1,2E-06	2,83E-07	2,3E-06
	Respiratory inorganics	Pt	5,31E-05	1,57E-05	1,82E-05	1,02E-05	8,99E-06
	Ionizing radiation	Pt	3,22E-07	8,1E-08	1,22E-07	5,3E-08	6,6E-08
	Ozone layer depletion	Pt	7,13E-08	4,53E-09	6,3E-08	1,83E-09	1,88E-09
	Respiratory organics	Pt	9,88E-08	1,75E-08	3,54E-08	1,14E-08	3,45E-08
	Carcinogens in food p.	Pt	0	0	0	0	0
	Recov. food calories	Pt	7,6E-09	1,56E-09	7,82E-10	2,64E-09	2,61E-09
	Non-carcin. in food p.	Pt	2,17E-12	2,17E-12	0	0	0
Ecosystem quality	Aquatic ecotoxicity	Pt	1,19E-05	1,17E-05	2,01E-07	2,72E-08	2,33E-08
	Terrestrial ecotoxicity	Pt	2,33E-06	7,29E-06	-7,9E-06	1,77E-06	1,18E-06
	Terrestrial acid/nutri	Pt	1,38E-06	4,3E-07	5,52E-07	2,11E-07	1,87E-07
	Land occupation	Pt	0,00023	5,29E-05	0,000177	9,02E-08	4,04E-07
Climate change	Global warming	Pt	6,1E-05	2,51E-05	1,09E-05	1,15E-05	1,35E-05
Resources	Non-renewable energy	Pt	6,26E-05	2,56E-05	1,46E-05	1,22E-05	1,01E-05
	Mineral extraction	Pt	2,42E-07	3,61E-08	1,71E-07	2,25E-08	1,29E-08

5.2 The integrated bioenergy chain with co-produced energies

5.2.1 Inventory analysis

In this paragraph the inventory of the scenario with integrated bioenergy represented through the co-product approach is described. In this case, the chain has been designed as a concatenation of the processes of single segments, each of which presents basically three products: the waste used to coproduce the energy, the electricity produced, and the heat produced. Furthermore, bioenergy consumption is not anymore represented as avoided consumption of fossil based energy, but co-produced energy are included as further inputs. Therefore, the process that represents the chain (Peach nectar, integrated bioenergy, farm to fork (co-product) (Tab. 5.7) is basically constituted by the consumption process (Peach nectar, consumed at integrated bioenergy house (coproduct)).

Tab. 5.7 The process Peach nectar, integrated bioenergy, farm to fork (co-product)

Product/s	Amount	Unit	Notes/Functional unit (FU)
Peach nectar, integrated bioenergy, farm to fork (coproduct)	0,99	l	Net peach nectar volume consumed = 1 brik of 1l x 0,99 (1% waste) = 0,99 l.
Materials/fuels			
Peach nectar, consumed at integrated bioenergy house (coproduct)	0,99	l	Peach nectar bought and consumed. Nectar consumed = 1 brik of 1l bought x 0.99 (1% waste) = 0.99 l.

Within the single segments, the following modifications have been included. In the consumption process (Peach nectar, consumed at integrated bioenergy house (coproduct)), electricity and heat cogenerated from biogas have been included as co-products economically allocated. Also nectar wasted is considered as a coproduct that is used in the modified processes for the production of the electricity and heat. Furthermore, the electricity co-produced is included as input in the refrigerator process (Tab. 5.8).

Tab. 5.8 The process Peach nectar, consumed at integrated bioenergy house (avoided prod.)

Products			
Peach nectar, consumed at integrated bioenergy house (avoided prod.)	0,99	l	FU: consumption of 1 brick of nectar per a total volume of 0,99l, including a 1% waste Economic allocation: 1,5€/l
Co-products			
Electricity from nectar consumption waste	0,023845	kWh	Total amount of electricitycoproduced. Economic allocation:0,15€/kWh
Heat from nectar consumption waste	0,148044	MJ	Total amount of heatcoproduced. Economic allocation:0,0167€/MJ
Nectar consumption waste	0,011164	kg	Total amount of nectar wasted Economic allocation:1,5€/l
Materials and fuels			

Peach nectar, at integrated bioenergy supermarket (coproduct)	1	p	Amount of nectar brik purchased at the supermarket
Electricity/heat			
Transport, passenger car/RER U	0,6	personkm	It is assumed a weekly purchase of 50 €, which includes a brik of 1,50€; transport is then economically allocated:1p*10km*2trips*1,5/50
Refrigerator, small, A (with electricity from coproduct)	3	l*day	Fridge use: 3dd (expiry date after opening)
Electricity, at cogen with biogas engine, agricultural covered, alloc. exergy/CH U (biogas from consumption waste)	0,023845114	kWh	FU: total electricity produced through the cogeneration from biogas from peach nectar wasted, calculated as in the processing segment but considering as feedstock the 0,011164 kg of unsold nectar
Heat, at cogen with biogas engine, agricultural covered, allocation exergy/CH U (biogas from consumption waste)	0,148043885	MJ	FU: total heat produced through the cogeneration from biogas from peach nectar wasted, calculated as in the processing segment but considering as feedstock the 0,011164 kg of unsold nectar
Social issues			
Recoverable food calories	6,47512	kcal	Food kcal calculated as in the distribution segment, considering a 1% waste
Waste to treatment			
Recycling PE/RER U (con elettricità)	0,013618797	kg	Calculated as in the distribution segment
Recycling aluminium/RER U (con scrap)	0,003235971	kg	-
Recyclingcardboard/RER U (con raccolta rifiuto)	0,047906829	kg	-

Similar changes have been done also in the distribution process (Peach nectar, at integrated bioenergy supermarket (coproducts)). Co-produced electricity and heat, as well as unsold nectar have been included, and used respectively by the retail process and by the energy production processes (Tab. 5.9Tab. 5.4 The process).

Tab. 5.9 The process Peach nectar, at integrated bioenergy supermarket (coproducts)

Products	Amount	Unit	Functional unit/Notes
Peach nectar, at integrated bioenergy supermarket (coproduct)	3660,03	p	FU: amount of nectar sold. It is assumed a 1% of unsold nectar which is treated as waste. Economic allocation as in the consumption.
Avoided products			
Electricity from distribution waste	88,156	kWh	Total amount of electricitycoproduced. Economic allocation: 0,15€/kWh
Heat from distribution waste	547,32	MJ	Total amount of heatcoproduced. Economic allocation: 0,0167€/MJ
Distribution waste	41,27331	kg	Total amount of nectar wasted Economic allocation: 1,5€/l
Materials and fuels			
Peach nectar, at integrated bioenergy plant (coproduct)	3697	p	Amount of processed nectar needed
Electricity/heat			
Transport, lorry 20-28t, fleet average/CH U	412733,1	kgkm	Transport of the nectar for 100 km from the processing plant
Retail (long time stor., room temp., large store) (IT)(with coproduced energy and conventional energy)	4127,331	kg	It represent the electricity and heat needed for a 1kg of goods distributed
Electricity, at cogen with biogas engine, agricultural covered, alloc. exergy/CH U (biogas from distribution waste)	88,156	kWh	FU: total electricity produced through the cogeneration from biogas from peach nectar wasted, calculated as in the processing segment but considering as feedstock the 41,27331 kg of unsold nectar
Heat, at cogen with biogas engine, agricultural covered, allocation exergy/CH U (biogas from distribution waste)	547,32	MJ	FU: total heat produced through the cogeneration from biogas from peach nectar waste, calculated as in the processing segment but considering as feedstock the 41,27331 kg of unsold nectar

Social issues			
Recoverable food calories	23938,52	kcal	Food wasted in the distribution. The amount of calories has been estimated basing on the the value of 58 kcal per 100g of nectar(Valfrutta n.d.)
Waste to treatment			
Recycling PE/RER U (con elettricità)	0,503487	kg	Recycle of the plastic part of the packaging with the inclusion of electricity consumption for collection.
Recycling aluminium/RER U (con scrap)	0,119634	kg	Recycle of the aluminium part of the packaging with the inclusion of electricity consumption for collection.
Recyclingcardboard/RER U (con raccolta rifiuto)	1,771115	kg	Recycle of the carboard part of the packaging with the inclusion of electricity consumption for collection.

Also in the processing (Peach nectar, at integrated bioenergy plant (coproducts)),energy produced has been included in the form of 2 coproducts, as well as the peach waste. In the single processes conventional energy consumption has been substitute by the ccoproduced electricity and heat (Tab. 5.10).

Tab. 5.10 The process Peach nectar, at integrated bioenergy plant (coproducts)

Products	Quantity	Unit	Functional unit/Notes
Peach nectar, at integrated bioenergy plant (coproducts)	3697	p	Functional unit: production of 3697 briks of 1l of nectar, for which 2,6282t of peaches have been used. The production of nectar implies the generation of 4 amounts of waste, which are considered for the end of life treatment.Economicallocation: 1.5€/p
Avoided products			
Electricity from nectar transformation waste	748,80	kWh	Total amount of electricitycoproduced fromnpeach processing waste. Economic allocation: 0.15€/kWh
Heat from nectar transformation waste	4648,98	MJ	Total amount of heatcoproduced from peach processing waste. Economic allocation: 0.0167€/MJ
Nectar transformation waste	0,35058	ton	Total amount of waste produced. Economic allocations: 0.01€/kg
Materials and fuels			
Peach, at integrated bioenergy farm	2,6282	ton	Amount of peaches needed

(with sub-processes - coproduct)			
Electricity/heat			
Peachwashing (coproduct)	2,628234	ton	FU calculated on the hypothesis that the selection implies a 2% waste referred to the amount of peaches that go into the stoning machine.
Peach selection(coproduct)	2,5767	ton	FU of the process calculate on the base of whole peaches weight.
Peach stoning(coproduct)	2,422098	ton	FU constituted by the weight of half peaches
Stoned peach selection(coproduct)	2,373658	ton	FU constituted by the weight of half peaches
Peach puree extraction(coproduct)	2,278752	ton	The FU is equal to the quantity of puree that can be extracted from the stoned peaches
Puree de-airing(coproduct)	2,2788	ton	FU: amount of puree de-aired
Pasteurization(coproduct)	2,2788	ton	FU: amount of pastorized puree
Acqueous solution mixing(coproduct)	1,848475	ton	FU: amount of acqueous solution mixed
Peach nectar mixing(coproduct)	4,1273	ton	FU: amount of puree and acqueousslution mixed
Puree de-airing(coproduct)	4,1273	ton	FU: amount of nectar de-aired
Peach nectar homogenization(coproduct)	3,696972	m3	FU: volume of nectar homogenizated (density equal to 1,1164 t/m3)
Pasteurization(coproduct)	4,1273	ton	FU: amount of nectar pastorized
Aseptic filling(coproduct)	3696,972	p	FU: number of 1l briks packaged
Electricity, at cogen with biogas engine, agricultural covered, alloc. exergy/CH U (biogas from transformation)	748,80	kWh	FU: total electricity produced through the cogeneration from biogas from peach processing waste, calculated as follows: - Amount of waste = 0.35058t - Biogas yield (from Biogas, from biowaste, at agricultural co-fermentation, covered/CH U) = 1m3/kg of fresh biowaste - Amount of biogas: 0.35058E3m3 - Allocation (Jungbluth et al. 2007): 0.861 - Biogas allocated on electricity: 301.85m3 - Amount of biogas needed to produce 1 kWh: 0,40311m3/kWh (Electricity, at cogen with biogas engine, agricultural covered, alloc. Exergy) - Total: 301.85m3/0,40311m3/kWh=748.8kWh
Heat, at cogen with biogas engine,	4648,98	MJ	FU: total heat produced through the cogeneration from

agricultural covered, allocation exergy/CH U (biogas from transformation)			biogas from peach processing waste, calculated as follows: - Amount of waste = 0.35058t - Biogas yield (from Biogas, from biowaste, at agricultural co-fermentation, covered/CH U) = 1m3/kg of fresh biowaste - Amount of biogas: 0.35058E3m3 - Allocation (Jungbluth et al. 2007): 0.139 - Amount of biogas needed to produce 1 MJ: 0,010482 m3/MJ (Heat, at cogen with biogas engine, agricultural covered, alloc. Exergy) - Total: 350.58*0.139/0,010482 m3/MJ=4648,98MJ
Social issues			
Recoverable food calories	7099,032	kcal	Amount of calories wasted in the peach selection

In the cultivation process (Peach, at integrated bioenergy farm (with sub-processes - coproducts)), both electricity and heat produced, as well asprunings have been included as coproducts, in order to substitute for fossil fuel consumption, and as input, to represent the damage deriving from prunings co-combustion. Furthermore, coproduced prunings are used to substitute industrial wood in order to produce chips for the cocombustion(Tab. 5.11).

Tab. 5.11 The process Peach, at conventional farm (with sub-processes- coproducts)

Products	Quantity	Unit	Comment/Notes
Peach, at conventional farm (with sub-processes-coproducts)	240	ton	*Functional unit*: peach production over 19 years of orchard lifetime, calculated basing on (Cerutti et al. 2010): - 0 tons from year 0 to year 3 (year 0 is the nursery) - Increasing from year 4 to year 5 = 8t/ha*a - Constant from 6 to 18: 16t/ha - Decreasing from year 19: 8t/ha*a = Year 19 Economic allocation: 2,5€/kg
Coproducts			
Electricity from peach prunings	3748,348	kWh	Total amount of electricitycoproduced from prunings. Economic allocation: 0.15€/kWh
Heat from peach prunings	355390,5	MJ	Total amount of heatcoproduced from prunings. Economic allocation: 0.0167€/MJ
Peach prunings	43,847	m3	Total amount of prunings (including end of life of the orchard). Economic allocations: 0.0025€/kg

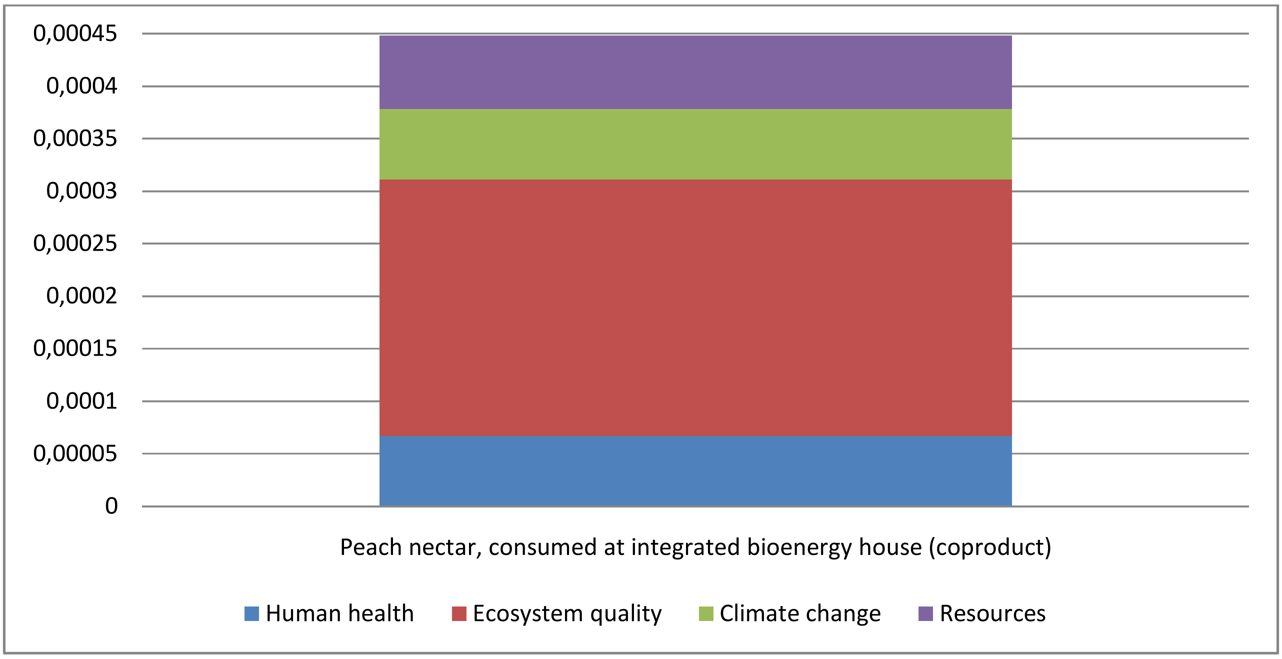
Resources			
Occupation, permanent crop, fruit	19	ha*a	Orchard lifetime: 19yy per 1 ha
Transformation, from pasture and meadow, intensive	0,29	ha	Original land use as pasture: 29%
Transformation, from arable, non-irrigated	0,71	ha	Original land use as not irrigate arable land: 71%
Transformation, to permanent crop, fruit	1	ha	Total land use: 1ha
Energy, gross calorific value, in biomass	284127,3	MJ	Total wood produced over the lifetime, calculated as: - Average trunk height: 0.60m with a section area of 0.0102m2 (Branzanti & Ricci 2001, p. 168); 3 main branches (lenght: 1.5m and section area: 0,0051m2); a further 10% of small branches, of which the 50% is cut each year; Wood density with 70% wet content: 900kg/m3; Roots, assumed to be the 25% of the total weight (Branzanti & Ricci 2001, p. 2) Total number of trees/ha (Fideghelli & Sansavini (eds.) 2005, p. 119): - Distance between the row: 5m - Distance between the threes: 3m - Number of threes: 666.66 Higher heating value: 7.2MJ/kg
Carbon dioxide, in air	21704,17	kg	Total CO2 uptake, calculated as function of carbon content in the wood: - Fresh wood weight: 39462kg - Dry wood weight: 39462*0.3 - Carbon content: 0.5kg/kg
Wood, hard, standing	43,84681	m3	Total wood volume
Peach wasted	4,8	ton	A 2% waste of uncollected peaches is assumed. In this process, this amount is simply reported as food waste and it is assumed to be left on the soil.
Materials/fuels			
Peach tree, at nursery	666,66	p	In this process, it is accounted all the damage related to the nursery process.
Electricity/heat			
Sub-process_Fertilization	240	ton	This process includes only the various inputs
Sub-process_Agro-processing	240	ton	This process includes only the various inputs
Sub-process_Pesticides	240	ton	This process includes only the various inputs
Electricity, low voltage, at grid/IT U	6935	kWh	Electricity consumption: 1 kWh per day per year is assumed, to account for the energy consumption of a shed
Heat, natural gas, at boiler condensing modulating >100kW/RER U	1058832	MJ	Heat consumption, calculate assuming a shed (3*4*3m) heated for 2h/d for 3 months/yy
Electricity, at cogen ORC 1400kWth, wood, emission control, allocation exergy/CH U (hardwood/mobile chop/prunings)	3748,348	kWh	The amount of electricity produced is proportional to the volume of chips that can be produced from the orchard wood and to the amount of chips needed to produced 1 kWhof electricity as allocated in the original multioutput process. In the specific, total heat is equal to: (18,411+25,436)/0,329*0,161/0,0057244

Heat, at cogen ORC 1400kWth, wood, emission control, allocation exergy/CH U(hardwood/mobile chop/prunings)	355390,5	MJ	The amount of heat produced is proportional to the volume of chips that can be produced from the orchard wood, to the amount of chips needed to produced 1 MJ of heat as allocated in the original multioutput process. In the specific, total heat is equal to: (18,411+25,436)/0,329*0,839/0,00031463
Social issues			
Recoverable food calories	1296000	kcal	Food calories waste with a 2% uncollected peach

5.2.2 Analysisof the integrated bioenergy chain with co-produced energies

In this paragraph, the main results of the weighting per single score of the process Peach nectar, integrated bioenergy, farm to fork (coproducts) are presented. In Fig. 5.2 it is reported the diagram per damage category. It is possible to note how avoided energies reduce quite sensitively the contribution of the **Non renewable energy** and **Climate change** categories in all the segments.

Fig. 5.2Diagram of the weighting with impact of the process Peach nectar, integrated bioenergy, farm to fork (coproduct)



More detailed data are listed in Tab. 5.12The weighting with IMPACT of the processPeach nectar, integrated bioenergy, farm to fork (coproduct), where results per each impact category are presented. In par. 5.3 a complete LCIA of this process in comparison with the conventional chain is reported.

Tab. 5.12The weighting with IMPACT of the processPeach nectar, integrated bioenergy, farm to fork (coproduct)

Damage category	Impact category	Unit	Total	Peach nectar, consumed at integrated bioenergy house (coproduct)
Total	Total	Pt	0,000448	0,000448
Human health	Carcinogens	Pt	5,52E-06	5,52E-06
	Non-carcinogens	Pt	6,57E-06	6,57E-06
	Respiratory inorganics	Pt	5,48E-05	5,48E-05
	Ionizing radiation	Pt	3,33E-07	3,33E-07
	Ozone layer depletion	Pt	7,18E-08	7,18E-08
	Respiratory organics	Pt	1,02E-07	1,02E-07
	Carcinogens in food p.	Pt	0	0
	Recov. food calories	Pt	7,56E-09	7,56E-09
	Non-carcin. in food p.	Pt	2,15E-12	2,15E-12
Ecosystem quality	Aquatic ecotoxicity	Pt	1,18E-05	1,18E-05
	Terrestrial ecotoxicity	Pt	2,34E-06	2,34E-06
	Terrestrial acid/nutri	Pt	1,41E-06	1,41E-06
	Land occupation	Pt	0,000228	0,000228
Climate change	Global warming	Pt	6,69E-05	6,69E-05
Resources	Non-renewable energy	Pt	6,95E-05	6,95E-05
	Mineral extraction	Pt	2,45E-07	2,45E-07

5.3 Impact analysis of comparison with the conventional peach nectar chain

In this paragraph, the results of the comparative LCA between the conventional peach nectar chain and the scenario previously described, are reported and analysed. As in par. 4.2, the LCIA is referred to the*functional unit* of 1 lt of produced, distributed, and consumed peach nectar. Likewise, also the method used is “IMPACT 2002 versione 240412 (catena alimentare)”.

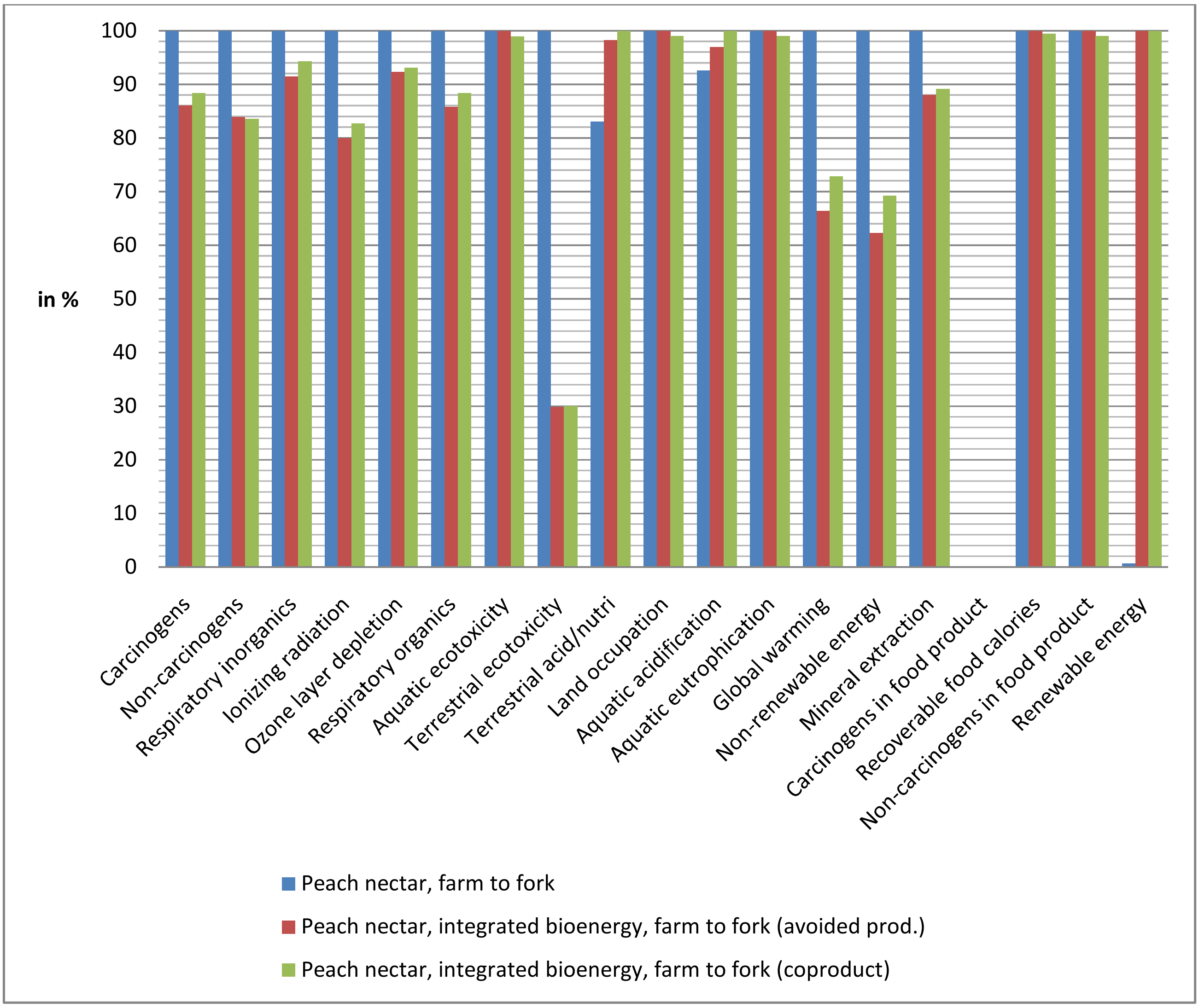
The processes studied are:Peach nectar, farm to fork (see par. 4.1), Peach nectar, integrated bioenergy, farm to fork (avoided prod.) (par. 5.1), and Peach nectar, integrated bioenergy, farm to fork (coproduct.) (par. 5.2), located in the database used at the following position: SimaPro3.3/Prof.originale/De Menna/fabio/processing/others/Peach Nectar.

The detailed results of the LCIA are reported in the following paragraphs according to the classic structure of the various phases, from characterization to damage assessment, normalization and weighting.

5.3.1 Characterization

In this paragraph, the results of the characterization are presented and analysed in a comparative perspective. In the specific, the characterizations of the three processes are confronted in order to underline the crucial changes in the damage. In the following figure (Fig. 5.3), this variations are shown in percentage terms, per each impact category, with reference to the process with the largest impact, while in the Tab. 5.13 the results in absolute terms are listed.

Fig. 5.3Diagram of the characterization with IMPACT of the comparison between the processesPeach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct)



It is possible to argue that the conventional chain presents the largest impacts in most of the categories, with the exception of **Terrestrial acidification/nitrification**, **Aquatic acidification**and **Renewable energy**, where the integrated bioenergy chain (in both the approaches) registers an higher impact. The reduction is larger in the case of **Terrestrial ecotoxicity** (around 70%), and in those categories particularly affected by energy consumption, as **Non-renewable** and **Global warming** (between the 27 and the 38%). On the contrary, a smaller reduction, between the 5 and 20%, is registered in the categories related to Human health (from **Carcinogens** to **Respiratory inorganics**).

Tab. 5.13Characterization per impact category of the processesPeach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct)

Impact category	Unit	Peach nectar, farm to fork	Peach nectar, integrated bioenergy, farm to fork (avoided prod.)	Peach nectar, integrated bioenergy, farm to fork (coproduct)
Carcinogens	kg C2H3Cl eq	0,01582677	0,013623521	0,013987936
Non-carcinogens	kg C2H3Cl eq	0,019905156	0,016712368	0,016629628
Respiratory inorganics	kg PM2.5 eq	0,000588634	0,00053842	0,000555189
Ionizing radiation	Bq C-14 eq	13,600024	10,867616	11,25571
Ozone layer depletion	kg CFC-11 eq	5,21E-07	4,81E-07	4,85E-07
Respiratory organics	kg C2H4 eq	0,000383375	0,000328884	0,000338962
Aquatic ecotoxicity	kg TEG water	3260,5153	3258,1327	3227,2929
Terrestrial ecotoxicity	kg TEG soil	13,517875	4,0312642	4,0539085
Terrestrial acid/nutri	kg SO2 eq	0,015379129	0,018182786	0,018507327
Land occupation	m2org.arable	2,8959183	2,8955875	2,8677935
Aquatic acidification	kg SO2 eq	0,003324108	0,003482235	0,00359035
Aquatic eutrophication	kg PO4 P-lim	0,31089723	0,31080305	0,30779481
Global warming	kg CO2 eq	0,90940761	0,6041406	0,66240142
Non-renewable energy	MJ primary	15,267096	9,5064585	10,565973
Mineral extraction	MJ surplus	0,041815115	0,03682559	0,03728341
Carcinogens in food product	kg C2H3Cl eq	0	0	0
Recoverable food calories	kcal	19,023175	19,023175	18,923581
Non-carcinogens in food product	kg C2H3Cl eq	5,50E-09	5,50E-09	5,45E-09
Renewable energy	MJ	0,020289376	2,931934826	2,932874319

In the categories **Aquatic ecotoxicity**, **Land occupation**, **Aquatic eutrophication**, **Recoverable food calories**, and **Non-carcinogens in food products**, it is possible to argue that the integration of bioenergy from waste does not lead to a damage reduction in the case of avoided products, while there's a slight reduction in the case of co-products, determined by the allocation of the damage also on the surplus amount of energy produced but not consumed in the chain. Nevertheless, it must be noted that this influence can be registered also in the other categories, but with different outcomes. In fact, in most of the categories, with the notable exception of **Non-carcinogens**, the "avoided products" scenario presents the largest reduction, because the energy produced compensates also the damage of a share of fossil energy which is not actually consumed. This damage reduction is larger than the one deriving from the allocation.

The results have been analysed also by looking at the main factors behind the variations in the specification per substances and processes, per each category. In **Carcinogens,**the conventional chain producesthe highest damage, with a14% reductionin the “avoided products” scenario, and a 12% in the “co-products” one. This can be explained mostly by the lower emission of *Hydrocarbons, aromatic* in air, in particular thanks to a reduction of the 43.5% of the contribution of Natural gas, at production onshore/NLandNatural gas, at production offshore/NL. Thus, the substitution of fossil fuel consumption with the self-generated bioenergy reduces the damage of the chain in this category, especially when energy is considered as an avoided product.

On the contrary, in **Non-carcinogens**,the lowest impact is registered in the “co-products” scenario, with a 16,5% reduction compared to the conventional chain, while the “avoided products” scenario shows a 16% decrease. In both the cases, there is a lower emission of *Arsenic* in soil, especially because organic waste is not composted anymore (process: Composting organic waste/RER (da Composting NL 1995(sub) di IVAMLCA3)), but is used as feedstock in the anaerobic digester, leading to the cogeneration of electricity and heat from biogas. Nevertheless, this reduction is partially compensated by an higher contribution to the emission of *Arsenic* in soil, deriving from the management of pruning combustion ashes(Disposal, wood ash mixture, pure, 0% water, to landfarming/CH) in the cultivation segment. The slight difference between the second two scenarios, which in this case is in favor of the “co-products” scenario, is caused by the allocation of some part of the related damage on the surplus energy.

In the category **Respiratory inorganics**,the total damage of the conventional chain (0.00058863 kg PM2.5 eq) decreases by the 8,5% in the “avoided products” case (0.00053842 kg PM 2.5 eq) and by the 5,7% in the “co-products” scenario (0,000555189 kg PM 2.5 eq). In both the cases, there is a reduction of *Nitrogen oxides*emissions in air, in particular because of the damage related to the processesHeavy fuel oil, burned in power plant/IT, Hard coal, burned in power plant/ITandNatural gas, burned in power plant/IT, which represents the main fossil fuels used in electricity production. Notable, this reduction occurs despite the damage deriving from the production of bioenergy, in particular from the co-combustion of prunings. In the case of co-produced energies, the allocation of damage on the surplus energy causes a lower influence both of the reduction of the damage of electricity consumption and of the damage produced by bioenergy processes.

In the **Ionizing radiation**category, the variation is higher: in fact, the damage in the “avoided products” and in the “co-products” case is respectively 20% and 11% lower than the conventional chain. The higher reductions in terms of substances have been found in the emission of *Radon-222* in air, in particular because of the lower importance of the process Tailings, uranium milling/GLO, and in the emission of *Carbon-14* in air, in particular because of the process Nuclear spent fuel, in reprocessing at plant/RER, which are attributable to the production of electricity for the national network. In both cases where bioenergy is produced and consumed, the reduction is thus determined by the avoided use of network electricity and by the surplus of energy not consumed.

The replacement of fossil energy with bioenergy is a relevant factor also in the category **Ozone layer depletion**.In fact, most of the reduction in the two hypothetical scenarios (around 7%) is due to the decrease of the emission of *Methane, bromochlorodifluoro-, Halon1211* inair, which is caused mainly by the process Transport, natural gas, pipeline, long distance/RU, related to the consumption of natural gas. As in the other categories, this emission is reduced in both the integrated bioenergy scenarios, but the damage is lower in the case of "avoided products" because the surplus of heat is assumed to compensate also the energy that is not actually consumed. Similarly, in the category **Respiratory organics**, where the conventional produces a damage of 0.00038338 kg C_2H_4 eq, the "avoided products" producesthe lower damage, mainly because of the reduced emission of *NMVOC, non-methane volatile organic compounds, unspecified origin* in air, which is caused by in particular by the processSweetening, natural gas/DE.

As far as the other 3 categories related to Human health are regarded, in **Carcinogens in food product** there is no variation given the absence of damage in the conventional chain, while in both **Non-carcinogens in food product** and **Recoverable food calories**, there is no variation for the "avoided products" chain, meaning that the substitution of energy *per se*does not produce any advantage. Nevertheless, in the "co-products" case, there is a slight reduction, which is totally due to the allocation of the damage on the surplus of energy that is not consumed in the system.

As in the case of **Non-carcinogens**, in **Aquatic ecotoxicity**thereduction of the damage is related to the end of life of organic waste, in both the alternative scenarios. Nevertheless, this reduction is particularly small, respectively - 0,18%and - 0,1%, because most of the impact in this category is caused by emission of *Fluvalinate* in water, during the cultivation of peaches (par. 4.2.1). Thus, the variation occurs mainly because of the lower emission of *Zinc*in soil, which is related to the processComposting organic waste/RER U (da Composting NL 1995 (sub) di IVAMLCA3). The damage due to *Zinc*diminishes because wastes are used to produce biogas, thus in both the scenarios there is an advantage deriving from the heavy metals absorption of biomass, which becomes prevalent, in absence of the compost, and in a minimal part, of the wastewater treatment emissions. However, it must be noted that the main byproduct of anaerobic digestion, the digestate, which contains a large part of the heavy metals contained in the feedstock, is represented in the bioenergy related processes as a co-product. This means that its use as soil fertilizer, with the related emissions, is not taken into account in the present analysis.Thus, if it was, there shouldn't be any relevant reduction in this category.As far as the difference between the “avoided products” and the “co-products”, it is explained by the allocation of damages deriving from the mentioned substance, which reduces the related damage in the second scenario.

In the category **Terrestrial ecotoxicity**, the conventional chain produces the highest damage (13.518 kg TEG soil), followed by the “co-products” scenario (4,0539 kg TEG soil) and by the “avoided products” one (4.0313 kg TEG soil). Also in this case, most of the damage reduction is determined by the different organic waste treatment, with the subsequent decrease in the emission of *Zinc*in soil, because of the absence of the composting process. It must be noted that in both the integrated bioenergy scenarios, this reduction compensates the increased damage caused by the emission of *Aluminium*in soil, deriving in particular from the processDisposal, wood ash mixture, pure, 0% water, to landfarming/CH, which represents the waste treatment of ashes from the co-generation from prunings (this process is present also in the conventional chian because it derives from the production of electricity from network). Furthermore, the emission of *Aluminium*in soil caused by the processDisposal, drilling waste, 71.5% water, to landfarming/CH, linked to the extraction of fossil fuels, is diminished by the substitution of non renewable energy with the generated bioenergy.

The**Terrestrial acid/nutri**category is one of the two categories where the integrated bioenergy scenarios present an increased damage. In fact, the “co-products” chain producesthe highest score (0.018507kg SO2 eq) while the conventional chain represents the best case (0.015379 kg SO2 eq). This depends mainly on the emission of *Ammonia* in air, which is caused in particular by the processBiogas, from biowaste, at agricultural co-fermentation, covered/CH U (with co-productsprocessing)and in the other processesdescribing the production of biogas from food chain waste. In the case of “avoided products”, this damage is lower mainly because of the effect of the avoided energyNatural gas, burned in industrial furnace >100kW/RER.

The substitution of fossil energy plays only a marginal role in the impact on**Land occupation**. In fact, the reduction registered in the “co-products” scenario is mainly caused by the allocation of some part of the damage of the*Transformation, to arable, non-irrigated*, deriving in particular from the processGreen manure IP, until April/CH, present in the glucose production, on the surplus of bioenergy that is not consumed in the system.A minimal reduction (0,012) is, nevertheless, also registered in the “avoided products” scenario because the avoided energy reduce the damage caused by *Transformation, to mineral extraction site*, which is linked mainly to the processWell for exploration and production, onshore/GLO/I.

In the category**Aquatic acidification**, the “co-products” scenario producesthe highest damage (0.0033241 kg SO2 eq) while the conventional chain presents the best performance (0.003602 kg SO2 eq), mainly because the emissions of *Ammonia*and*Hydrogen sulfide* in air increase as a result of the biogas production process, in particular in Biogas, from biowaste, at agricultural co-fermentation, covered/CH U (con coprodottotrasformazione). The chian with avoided products presents a lower damage because of the "avoided" emissions of *Sulfur dioxide*and*Nitrogen oxides*caused by the processHeavy fuel oil, burned in power plant/IT, which are reduced by the avoided consumption of electricity from network, especially in the case of surplus.

In **Aquatic eutrophication** there is only a slight reduction of the damage in the case of "avoided products" (-0,031%), while there is an higher reduction (- 1%) in the "co-products" scenario, caused by the allocation on the surplus of co-produced energies. Obviously, most of this reduction regards the emission of *Phosphorus* in water, which is related to the cultivation phase.

As far as greenhouse gas emissions are regarded, the category **Global warming**is characterized by a high variation, as a result of the substitution of fossil energy with bioenergy. In fact, there is a reduction of the 27,2% and of the 33,6%, respectively in the "co-products" and in the "avoided products" scenario. Most of this decrease is caused by the lower emission of *Carbon dioxide, fossil* in air, in particular in the processNatural gas, burned in boiler condensing modulating >100kW, which is part of the energy inputs of the cultivation segment. This reduction happens in both the hypothetical scenario as a result of the self-generated and consumed bioenergy. Furthermore, this effect is higher in the "avoided products" scenario because the surplus of energy that is not consumed, in this case, reduces the damage more than the allocation in the "co-products" scenario.Furthermore, it must be noted that this reduction is partially compensated by the higher emission of *Dinitrogen monoxide* in air, which is mainly due to the processBiogas, from biowaste, at agricultural cofermentation, covered/CH, as well as the others process of bioenergy production. In this case, the "co-products" scenario shows a slight advantage in terms of damage because of the allocation. Infact, the allocation of the damage on the surplus energy reduces the influence of the mentioned process, which is part of the bioenergy production processes that are used as inputs.

Obviously, the effect of the fossil energy substitution is higher in the category **Non renewable energy**. In particular, while the conventional chain uses 15.267 MJ primary, the "co-products" chain requires only 10.566 MJ primary (-30,8%), and the "avoided products" only 9.507 MJ primary (-37,8%). Most of the reduction is related to the extraction of *Gas natural, in ground*, in particular in the processNatural gas, at production onshore/RU, which is part of the processes of electric and thermal energy production. As in most of the categories, a common part of the reduction is imputable to the substitution of fossil energy with the self-generated and consumed bioenergy, while the difference between the two hypothetical scenarios depends on the methodological approach used to represent the surplus of energy, which is not consumed. A crucial aspect that should be underlined is the indirect effect of the substitution in terms of life cycle energy consumption. In fact, the difference of MJ between the conventional and the integrated bioenergy chains does not represent the amount of bioenergy produced. In the following table (Tab. 5.14) it is shown the total amount of electricity and heat produced in each segment of the chain, referred to the functional unit analysed (1l of peach nectar).

Tab. 5.14 Bioenergy produced per liter of peach nectar and segment of the chain

Segment	Electricity (in MJ)	Heat (in MJ)	Total (MJ)
Cultivation	0,040	1,052	**1,092**
Processing	0,729	1,258	**1,987**
Distribution	0,087	0,150	**0,236**
Consumption	0,087	0,150	**0,236**
Total	0,943	2,609	**3,551**

From the figure, it is possible to note how in the integrated bioenergy chain it is possible to produce a maximum amount of energy equal to 3,551 MJ/lt of peach nectar, which represents the 23% of the total direct and indirect fossil energy consumption. The use of this energy obviously creates an advantage which can be different depending on the criteria used to define the produced energies. In both cases, the damage reduction in **Non-renewable Energy**caused by self-consumption is higher than the value of the energy produced because 2.8028MJ/MJ are needed to produce 1 unit of electricity and 1.2289MJ/MJ to produce 1 unit of heat [3].

Besides, it must taken into account the **Renewable energy** consumed. It must be noted that in this category, it is also included the bioenergy self-consumed, as well as the consumption of renewable energy from the network. As far as the last is regarded, it must be noted a reduction of *Energy, kinetic (in wind), converted*, which is the main source of the processElectricity, at wind power plant 800 kW/RER. As far as integrated bioenergy is regarded, its consumption is equal to 2,918507 MJ (result of the sum of the process contribution of the 8 energies co-produced and consumed). It is possible to note how this figure is lower than the total bioenergy produced, and how the total surplus is equal to 0,632 MJ/lt of peach nectar. As resulting from the LCI (see par. 5.2.1), this surplus is deriving from mainly from the un-used heat in the processing segment.

Similarly, the damage in the **Mineral extraction**category is reduced by the lower impact of *Water, cooling, unspecified natural origin/m3*, which is mainly used by the process Heavy fuel oil, burned in power plant/IT, as well as other energy production processes. In the specific, the “avoided products” and the “co-products”

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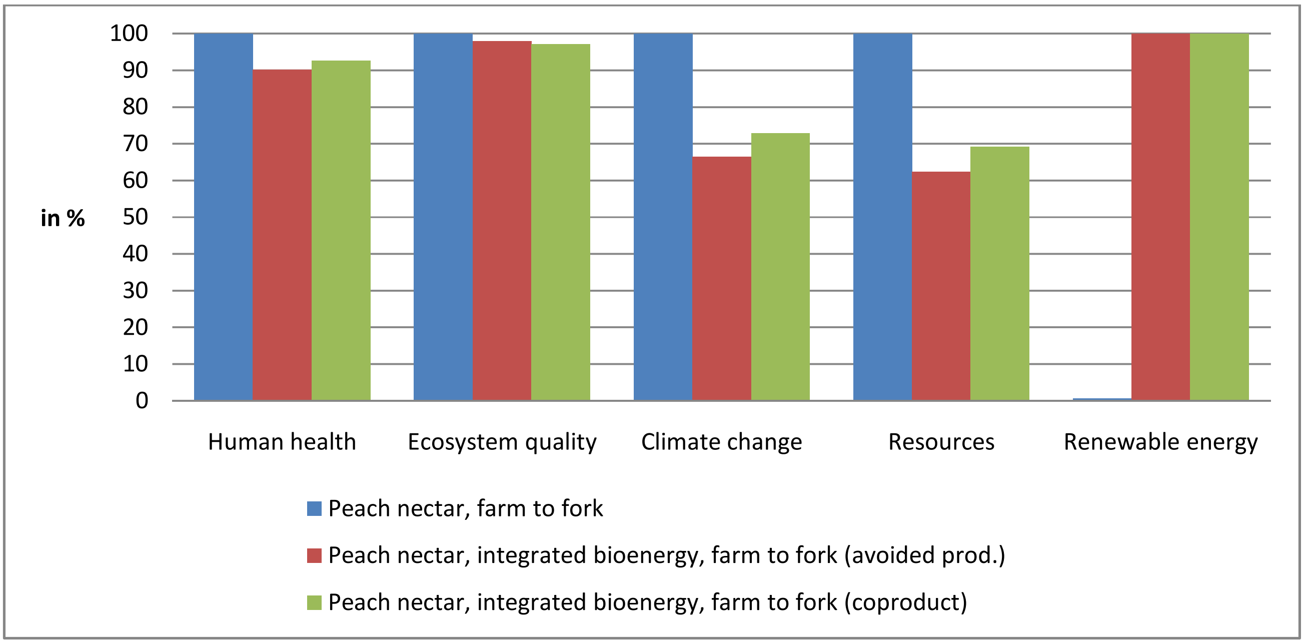
[3] These data have been extrapolated by analyzing,with the same method, respectively 1 kWh of electricity from network and and 1 MJ of heat from natural gas combustion (see par. 6)

scenarios guarantee, respectively a 12% andan 11% reduction. Also in this case, the difference between the two scenario is explained by the methodological approach used to represent the energy produced.

5.3.2 Damage assessment

In this paragraph, the results of the comparative damage assessment are presented and discussed, both in terms of percentage variations and in terms of most relevant substances and/or processes.

Fig. 5.4Diagram of the damage assessment of the processes Peach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct)



The figure Fig． 5.4shows the main changes between the three processes confronted, with reference to the process with the largest impact, per each of the 5 damage categories.It is possible to argue how the integrated bioenergy scenario reduces the damage in all the categories with the exception of **Renewable energy**, where the consumption of self-produced electricity and heat lead to a higher score. For the same reason, the highest relative reduction is registered in the **Resources** category, where the damage is respectively 30 (“co-products”) and 37% (“avoided products”) lower than the conventional chain. A similar reduction, respectively 27 and 33%, can be registered also in the **Climate change** category. The effect of energy source substitution is less evident in the categories **Human health**, where the maximum reduction is lower than the 10% (“avoided products”), and **Ecosystem quality**, which is the only category where the “co-products” scenario presents the best performance, with a 3% reduction. In Tab. 5.15 the absolute scores per damage and impact category of the three processes are shown.

Tab. 5.15Damage assessment per impact category of the processesPeach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct)

Damage category	Impact category	Unit	Peach nectar, farm to fork	Peach nectar, integrated bioenergy, farm to fork (avoided prod.)	Peach nectar, integrated bioenergy, farm to fork (coproduct)
Human health	Carcinogens	DALY	4,43E-08	3,81E-08	3,92E-08
	Non-carcinogens	DALY	5,57E-08	4,68E-08	4,66E-08
	Respiratory inorganics	DALY	4,12E-07	3,77E-07	3,89E-07
	Ionizing radiation	DALY	2,86E-09	2,28E-09	2,36E-09
	Ozone layer depletion	DALY	5,47E-10	5,06E-10	5,09E-10
	Respiratory organics	DALY	8,17E-10	7,01E-10	7,22E-10
	Carcinogens in food product	DALY	0	0	0
	Recoverable food calories	DALY	5,39E-11	5,39E-11	5,36E-11
	Non-carcinogens in food product	DALY	1,54E-14	1,54E-14	1,53E-14
Ecosystem quality	Aquatic ecotoxicity	PDF*m2*yr	0,16367787	0,16355826	0,1620101
	Terrestrial ecotoxicity	PDF*m2*yr	0,10692639	0,0318873	0,032066417
	Terrestrial acid/nutri	PDF*m2*yr	0,015994294	0,018910098	0,019247621
	Land occupation	PDF*m2*yr	3,1565509	3,1561904	3,1258949
Climate change	Global warming	kg CO2 eq	0,90940761	0,6041406	0,66240142
Resources	Non-renewable energy	MJ primary	15,267096	9,5064585	10,565973
	Mineral extraction	MJ primary	0,041815115	0,03682559	0,03728341
Renewable energy	Renewable energy	MJ	0,020289376	2,931934826	2,932874319

As far as **Human Health**is regarded, the “avoided products” scenario has the lower damage, compared to the other processes, with a difference of 0,5099E-7 DALY. Most of this is due to the reduction of the emission of*Sulfur dioxide* in air, which is caused by fossil fuel combustion in power plants. In both the integrated bioenergy scenarios, this emission is reduced respectively by avoided energy and by the use of coproduced energies and the allocation of surplus. Despite a relevant decrease, in all the three cases, the most impacting category is **Respiratory inorganics**.

In the category **Ecosystem quality**, the main factor of the damage reduction is constituted by the absence of emissions related to composting production, such as *Zinc*, which seems to influence mostly the impact on **Terrestrial ecotoxicity**, where most of the reduction is located. As far as the difference between the two hypothetical scenarios is regarded, it must be noted that this variation is almost entirely related to **Land occupation**, which is the impact category with the highest score. In this category, the allocation of the damage on the surplus energy that is not consumed determines therefore an advantage for the “coproducts” scenario.

In the other categories, while for **Climate change**and **Renewable energy** the damage assessment corresponds to the characterization, in the case of **Resources** it is possible to note how the category with the highest impact in all the three processes is constituted by Non-renewable energy, which is also the category where most of the damage reduction is found.

5.3.3 Normalization

The results presented in this paragraph show the changes in the normalization, according to IMPACT2002+, with reference to the average damage of the human activities in Europe (see Par. 3.4). Given the comparative perspective of this part of the analysis, results do not provide an insight of the changes in the relative contribution of the individual chain segments, but compares the three chains in each damage category.

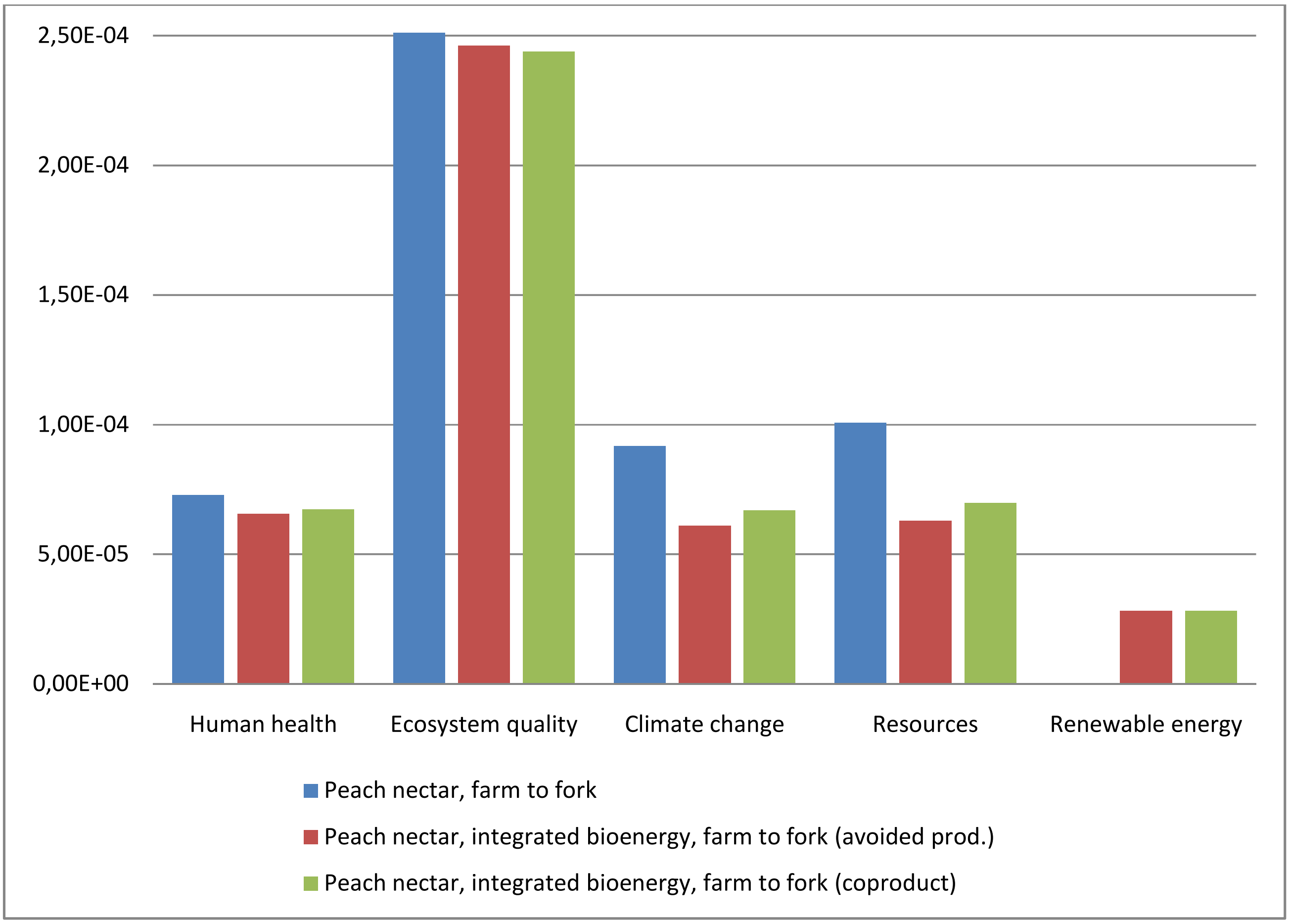
As reported in Tab. 5.16, in **Human Health** the relative impact of the chain is reduced in the alternative scenarios. The “avoided products” chain is characterized by the lowest damage, which is equal to 6,5618E-5 times the damage produced in the same category by the human activities in one year and per one citizen. In **Ecosystem quality**the “co-products” scenario, which presents the best performance for the reasons already mentioned, produces a damage, which is 0,00024376 times the reference term.In **Climate change**the “avoidedproducts” determines a reduced damage that is equal to 6,1018E-5 times the reference damage. This reduction is similar to the one registered in **Resources**. As far as **Renewable energy**is regarded, it is possible to see how the ratio between the chain analyzed and the reference damage increases by almost 150 times.

Tab. 5.16Normalization per impact category of the processes Peach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct)

Damage category	Impact category	Peach nectar, farm to fork	Peach nectar, integrated bioenergy, farm to fork (avoided prod.)	Peach nectar, integrated bioenergy, farm to fork (coproduct)
Human health	Carcinogens	6,25E-06	5,38E-06	5,52E-06
	Non-carcinogens	7,86E-06	6,60E-06	6,57E-06
	Respiratory inorganics	5,81E-05	5,31E-05	5,48E-05
	Ionizing radiation	4,03E-07	3,22E-07	3,33E-07
	Ozone layer depletion	7,72E-08	7,13E-08	7,18E-08
	Respiratory organics	1,15E-07	9,88E-08	1,02E-07
	Carcinogens in food product	0	0	0
	Fabbisognocaloricorecuperabile	7,60E-09	7,60E-09	7,56E-09
	Non-carcinogens in food product	2,17E-12	2,17E-12	2,15E-12
Ecosystem quality	Aquatic ecotoxicity	1,19E-05	1,19E-05	1,18E-05
	Terrestrial ecotoxicity	7,81E-06	2,33E-06	2,34E-06
	Terrestrial acid/nutri	1,17E-06	1,38E-06	1,41E-06
	Land occupation	0,000230428	0,000230402	0,00022819
Climate change	Global warming	9,19E-05	6,10E-05	6,69E-05
Resources	Non-renewable energy	0,000100457	6,26E-05	6,95E-05
	Mineral extraction	2,75E-07	2,42E-07	2,45E-07
Renewable energy	Renewable energy	1,94E-07	2,81E-05	2,81E-05

In the following figure (Fig. 5.5Diagram of the normalization (per damage category) of the processes Peach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct)), the results of the normalization per damage category and per process are shown.

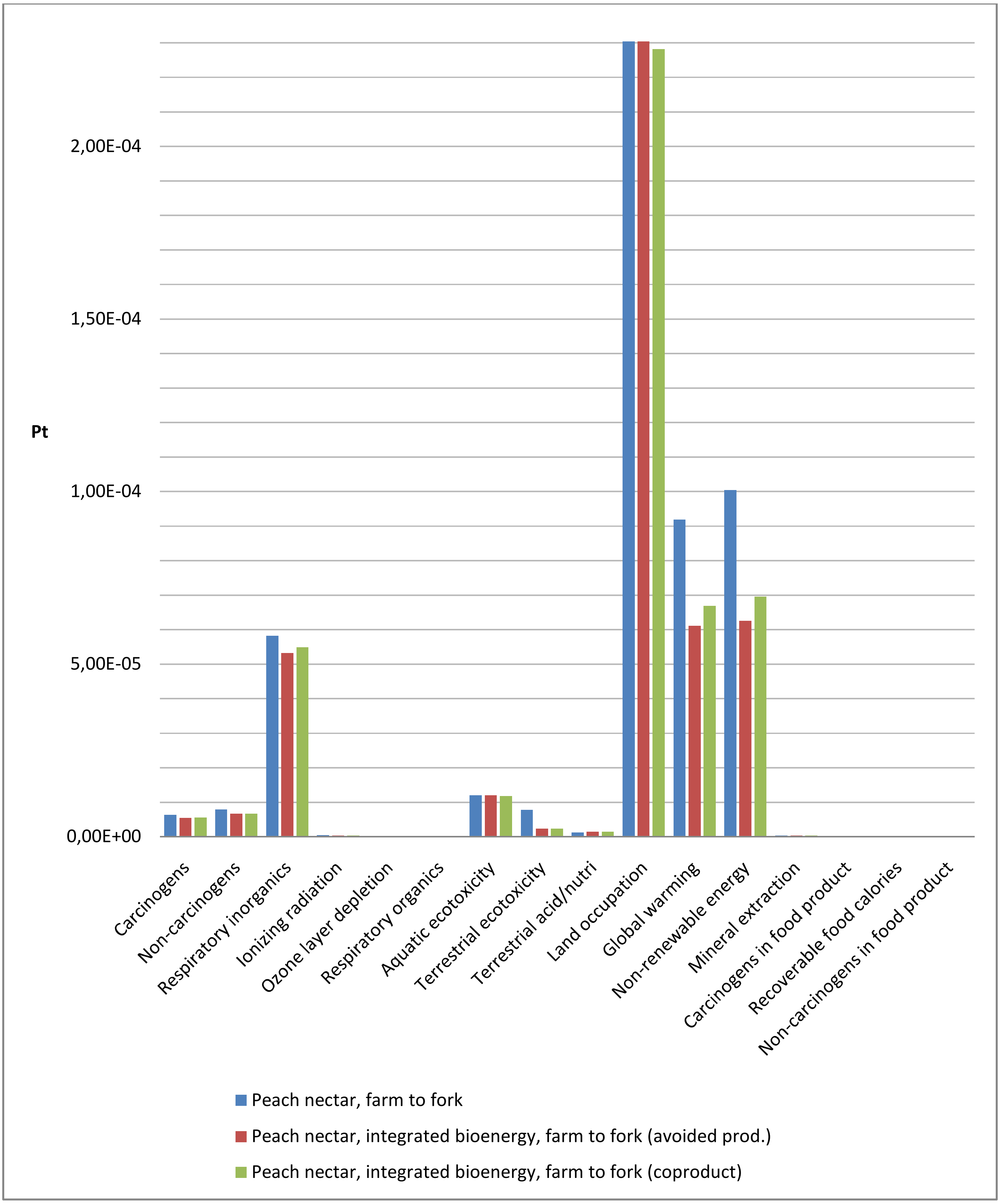
Fig. 5.5Diagram of the normalization (per damage category) of the processes Peach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct)



5.3.4 Weighting and Single Score

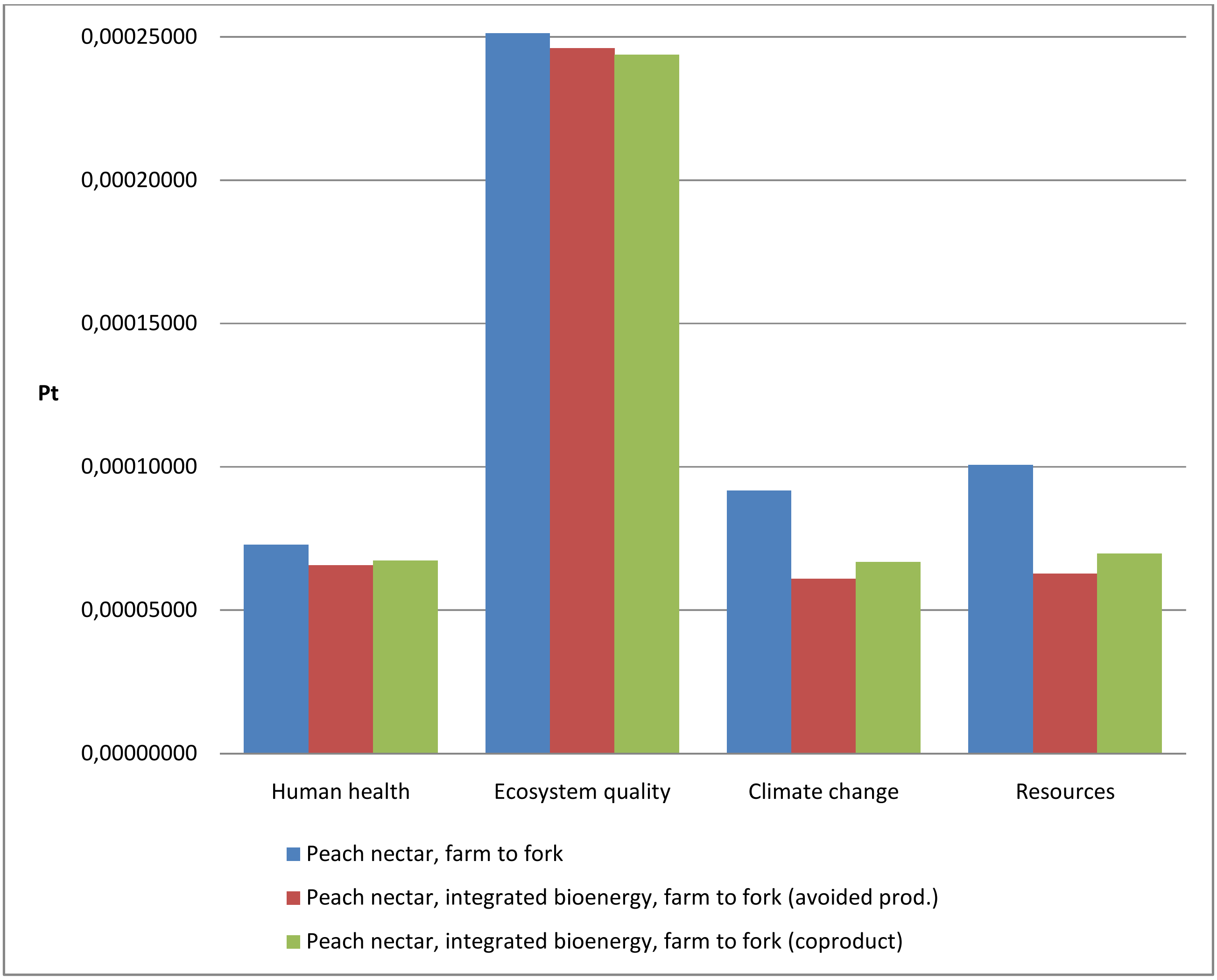
In this paragraph the results of the comparison in terms of single score are presented. In the Fig. 5.6Diagram of Weighting per Impact Category of the processes Peach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct) it is shown the comparison of the weighting per Impact category between the three processes, in absolute terms. As already mentioned, Land occupation represents the most relevant category also in the integrated bioenergy scenario, given that the only reduction is determined by the allocation in the “co-products” scenario. Major reductions are concentrated in the categories directly and indirectly related to energy consumption, while minor variations can be registered in the Human health categories.

Fig. 5.6Diagram of Weighting per Impact Category of the processes Peach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct)



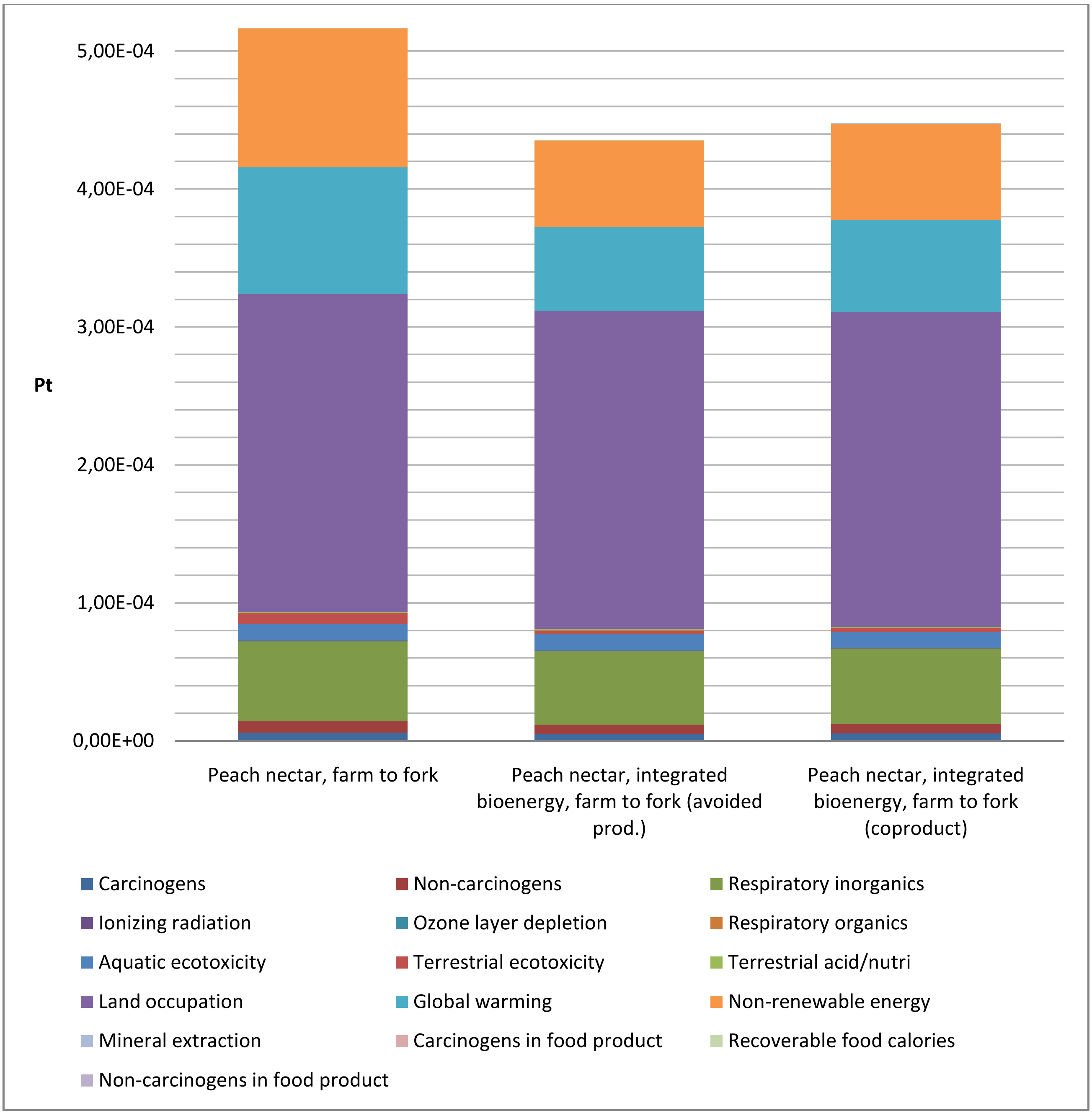
In the following diagram (Fig. 5.7Diagram of Weighting per damage category of the processes Peach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct)), the weighting of the three processes, expressed in points of damage, is compared according to the 4 relevant categories. As argued in the previous paragraphs, the substitution of fossil energy has a limited influence on the **Human health** and **Ecosystem quality** scores, but it determines the reduction in the other two categories. Furthermore, the “co-products” scenario has a lower impact than the “avoided products” only in **Ecosystem quality**, while in the case of **Climate change** and **Resources**, it has a higher impact mainly because the surplus energy that is co-produced but not consumed exits from the system and the allocation of the damage creates only a marginal advantage, which is lower than the advantage guaranteed by avoided energies.

Fig. 5.7Diagram of Weighting per damage category of the processes Peach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct)



In the Fig. 5.8the comparison in absolute terms between the single scores of the three processes analyzed, with the relative contribution of each impact category, is reported, while in Tab. 5.17single scores per category are presented.

Fig. 5.8Diagram of single score of the processes Peach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct)



It is possible to note how the total damage is equal to 0,00051674 Pt in the conventional chain, followed by the 0,00044783 Ptin the “co-products” scenario, with a 13,33% reductionin respect to the conventional chain, and by the 0,00043548 Pt in the “avoided products” scenario, which is 15,73% lower than the first case and 2,76% lower than the second, as shown in Tab. 5.18.

Tab. 5.17The weighting per single score per impact category of the processesPeach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct)

Damage category	Impact category	Unit	Peach nectar, farm to fork	Peach nectar, integrated bioenergy, farm to fork (avoided prod.)	Peach nectar, integrated bioenergy, farm to fork (coproduct)
Total	Total	Pt	0,00051674052	0,00043548097	0,00044783438
Human health	Carcinogens	Pt	6,25E-06	5,38E-06	5,52E-06
	Non-carcinogens	Pt	7,86E-06	6,60E-06	6,57E-06
	Respiratory inorganics	Pt	5,81E-05	5,31E-05	5,48E-05
	Ionizing radiation	Pt	4,03E-07	3,22E-07	3,33E-07
	Ozone layer depletion	Pt	7,72E-08	7,13E-08	7,18E-08
	Respiratory organics	Pt	1,15E-07	9,88E-08	1,02E-07
	Carcinogens in food p.	Pt	0	0	0
	Recov. food calories	Pt	7,60E-09	7,60E-09	7,56E-09
	Non-carcin. in food p.	Pt	2,17E-12	2,17E-12	2,15E-12
Ecosystem quality	Aquatic ecotoxicity	Pt	1,19E-05	1,19E-05	1,18E-05
	Terrestrial ecotoxicity	Pt	7,81E-06	2,33E-06	2,34E-06
	Terrestrial acid/nutri	Pt	1,17E-06	1,38E-06	1,41E-06
	Land occupation	Pt	0,000230428	0,000230402	0,00022819
Climate change	Global warming	Pt	9,19E-05	6,10E-05	6,69E-05
Resources	Non-renewable energy	Pt	0,000100457	6,26E-05	6,95E-05
	Mineral extraction	Pt	2,75E-07	2,42E-07	2,45E-07

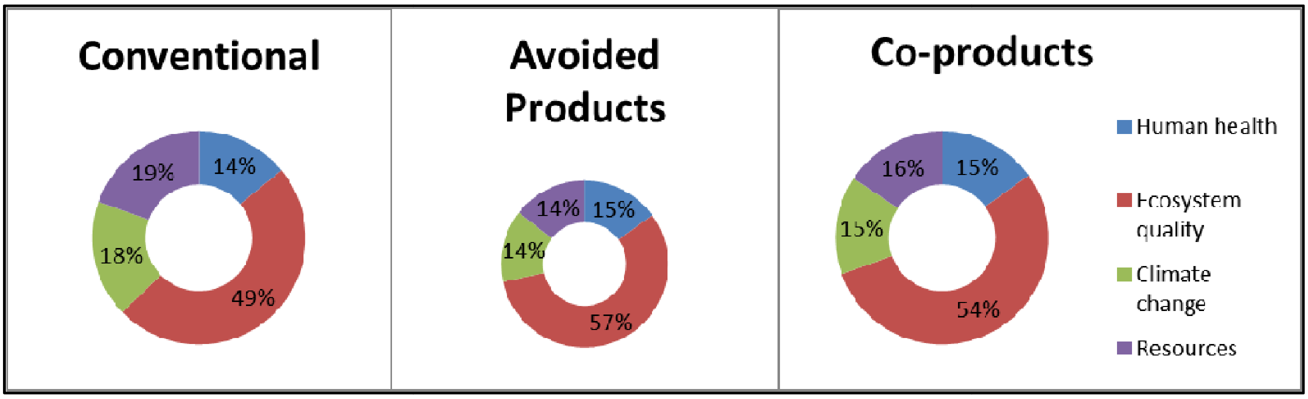
As far as damage categories are regarded, the observed reductions have direct consequences in terms of damage composition (

Fig. 5.9). In fact, while in the conventional chain almost the 50% of the total score is due to the category**Ecosystem quality**, followed by **Resources**, **Climate change**and**Human health**, in the “avoided products" and"co-products" scenarios, the contribution of **Ecosystem quality**, despite its descrease in absolute terms, has an higher relevance. This change is directly caused by the larger reduction in the categories **Climate change**and**Resources**: this highlights how the integrated bioenergy production and their self-consumption has more advantages in terms of resource consumption and greenhouse gas emissions, than in terms of human and ecosystem well being.

Tab. 5.18Comparison of the weighting per single score per damage category of the processes Peach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct)

	Conventional	Avoided Products		Co-products	
Category	Pt	Pt	% from convent.	Pt	% from convent.
Human health	0,00007281	0,00006562	-9,87	0,00006740	-7,43
Ecosystem quality	0,00025135	0,00024605	-2,11	0,00024376	-3,02
Climate change	0,00009185	0,00006102	-33,57	0,00006690	-27,16
Resources	0,00010073	0,00006279	-37,66	0,00006977	-30,74
Total	0,00051674	0,00043548	-15,73	0,00044783	-13,33

Fig. 5.9 Comparison of damage composition



5.4 Main results and discussion

The integration of bioenergy from waste in the food chain could lead to substantial environmental benefits in those cases where the renewable energy produced is directly used to substitute electricity from network and heat from natural gas combustion. Nevertheless, it must be beared in mind that there is a substantial difficulty to achieve a complete energetic independence in the agro-food chain with the sole use of food waste and byproducts.

6 Not integrated agro-energetic system

As argued in the previous chapter, most of the environmental advantages deriving from the integration of bioenergy in the agro-food chain are directly related to the possibility to substitute a large part of the consumption of electricity and heat produced with fossil fuels. In fact, only when self-consumption is assumed, these benefits can be attributed to the analyzed food chain. Nevertheless, bioenergy production from food waste is more often seen and implemented as a secondary economic activity (and product), aimed at increasing the whole profitability of the agro-food production, especially where net metering or subsides are foreseen. Usually, agricultural producers or food industries either produce and sell the bioenergy directly to national/local energy companies through the grid, or sign agreements with bioenergy producers for the sole supply of feedstock.

From the environmental perspective, in both cases, the typology of energy consumption in the agro-food chain does not change, but, given that either energy or byproducts are sold, the overall damage can be partly allocated on these products, leading to a proportional damage reduction of the food product/s.In the specific, it can be argued that in the first case the environmental impact of the agro-food chain increases because of the inclusion of bioenergy production processes, and then decreased by allocation: thus, the damage reduction is closely related to the efficiency and productivity of bioenergy production. It must be noted that when bioenergy is sold to the grid, it becomes part of the national energy mix, marginally decreasing the damage deriving from the network electricity. This systemic change should be therefore taken into account in the LCA of multi-output processes where net metering is foreseen.

On the other side, when feedstock (such as prunings) is sold, the damage allocation is proportional to the amount of biomass removed, with an effect on the final impact of the agro-food chain, which depends on several factors, such as soil fertility and heavy metal contents, as well as the chosen analysis method. The damage allocated on the co-produced feestock becomes part of the bioenergy production processes, which are usually considered as a different system, with its own boundaries and functional unit. Nevertheless, from the agro-food sector perspective, this system can not be seen as totally separated, especially when located in the same areas. In fact, bioenergy production, although not integrated, is usually located near the production of feedstock, in order to decrease logistic costs, and this has direct consequences in terms of local impacts, as well as benefits. Furthermore, bioenergy is actually becoming an integral part of sectorial activities, coherently with the multifunctional feature of agriculture.

Therefore, in this research, it has been also analyzed a system where agro-food chain and bioenergy production are both included even if not integrated. This scenario has been thus compared to the previously discussed scenarios, in order to derive some indication on the overall impact of food and energy production, based on the same inputs (land, energy, water, etc) and on the same functional unit. In this chapter, the results of this analysis are presented and discussed. In particular, in the first two paragraphs the inventory of the not integrated agro-energetic system and its analysis are presented. In the third paragraph, it is reported the comparison with the other scenarios previously described. In the fourth and fifth paragraph, the electricity and heat produced with peach chain waste are compared to the electricity from network and the heat from natural gas. Finally, main results are summarized and discussed in terms of policy indication.

6.1 The not integrated agro-energetic system

6.1.1 Inventory analysis of not integrated system

The not integrated agro-energetic system, hereafter "not integrated" scenario, has been represented through the processPeach nectar, farm to fork (not integrated). The functional uniti s constituted by the 3623,4 ltof peach nectar consumed, but it includes also the corresponding productions of electricity and heat, respectively amounting at 964,4 kWh and 9624,5 MJ.

The process is composed by the following 3 sub-processes:

- Peach nectar, consumed at house (coproduct) (not integrated), which represents the peach nectar chain (from farm to fork) in which the waste and byproducts are considered as co-products that exit from the chain and are treated by one or more external enterprises in order to cogenerate electricity and heat to be sold to the network. It must be underlined how the agro-food chain damage, in this case, is comparable to the conventional chain, because the energy used is the same (electricity from network and heat from natural gas), but it is reduced by the presence of co-produced wastes, which have been allocated according to the economic criteria.

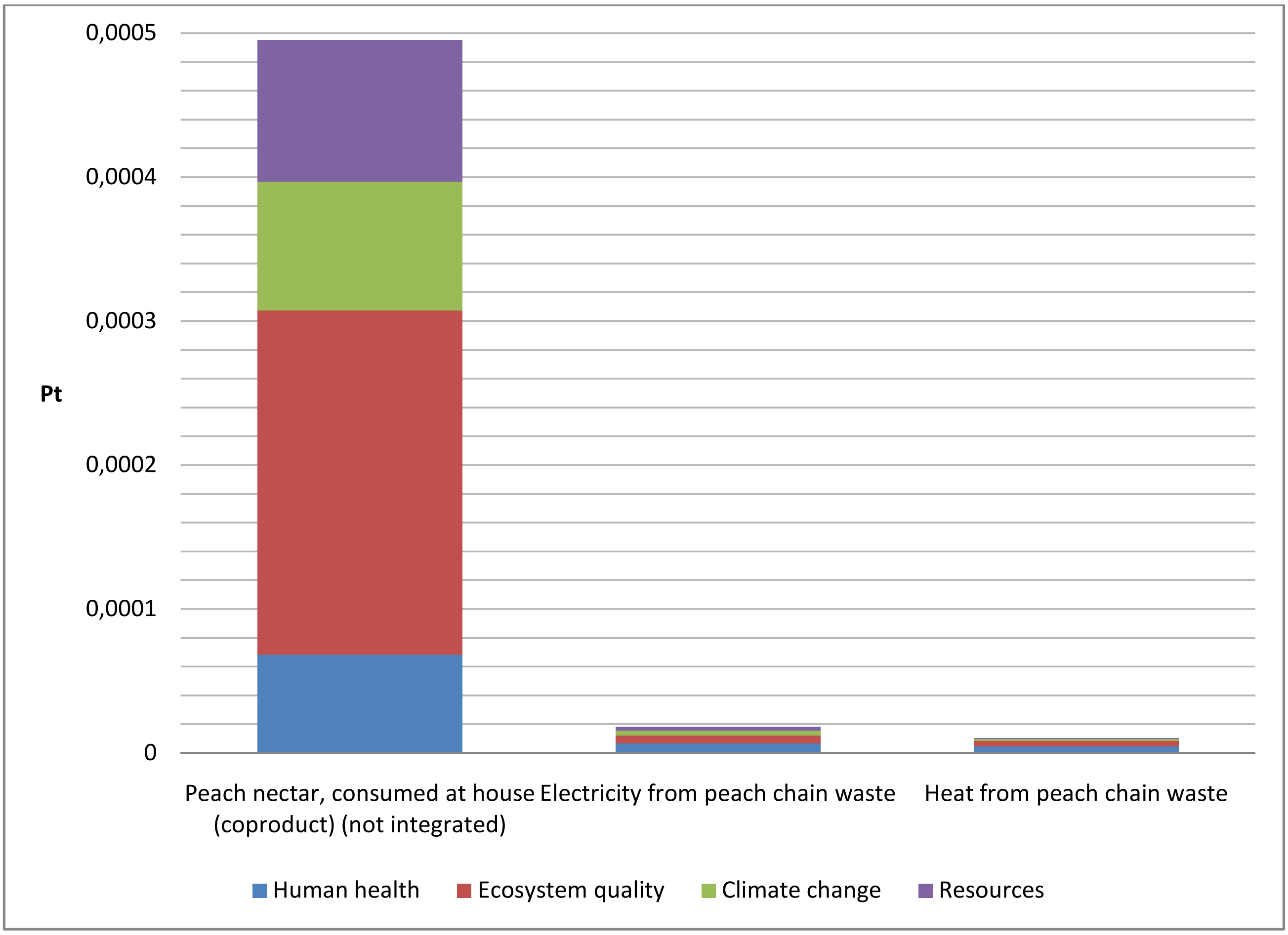
- Electricity from peach chain waste, which represents the whole processes of electricity production from the mentioned coproduced waste. Therefore, part of the impact of this process is deriving from the agro-food chain, for a share equal to the allocation used. Futhermore, it must be highlighted how, differently from the integrated scenario (both in the "avoided products" and in the "co-products" case), damages deriving from the cogeneration processes (energeticaly allocated as in the original Ecoinvent database processes) are entirely attributed to the energy produced.
- Heat from peach chain waste, which encoompasses all the processes of heat production from the mentioned co-produced waste. As for the electricity, also in this process part of the total damage derives from the peach nectar chain, while the remaining damage derives from the cogeneration processes, according to the allocation used in the database.

As already argued, if considering only the first process (the agro-food chain), the production of peach nectar damage would decrease, by including in the system also the energy processes two main effect can be predicted: on one hand, the damage reduction determined by the allocation of co-produced waste is likely to disappear; on the other hand, the inclusion of their new hypothetical treatment is likely to produce an overall increase of the damage, as well as the effect of the absence of self-consumption. In the following paragraphs, both the results of the analysis of the processPeach nectar, farm to fork (not integrated), and of its comparison with the conventional and integrated bioenergy scenario are presented.

6.1.2 Environmental impact of the not integrated bioenergy and peach nectar chain

In this paragraph the analysis of environmental impacts associated with the not integrated agro-energetic systems is presented. In particular, the main results in terms of single score are reported and discussed, in order to identify the most relevant processes and substances. The diagram in Fig. 6.1 shows the weighting per single score of the process Peach nectar, farm to fork (not integrated), according to the IMPACT2002+ method. The highest impact in the system is associated with the agro-food production, which is characterized by a damage distribution similar to the conventional chain, while the processes representing energy production play only a marginal role.

Fig. 6.1Diagram of the weighting per single score of the process Peach nectar, farm to fork (not integrated)



The Tab. 6.1 shows the results of the weighting per single score in absolute terms. From these data it is possible to note that the total damage of the system, per lt of peach nectar produced is equal to 0.00052352 Pt. Around the 95% of the total is due to the process Peach nectar, consumed at house (coproduct) (not integrated), which represents the agro-food chain. Another 3% is caused by the production of electricity (Electricity from peach chain waste), while heat production determines around the 2% of the system damage.

Tab. 6.1The weighting per single score per impact category of the processPeach nectar, farm to fork (not integrated)

Damage category	Impact category	Unit	Total	Peach nectar, consumed at house (coproduct) (not integrated)	Electricity from peach chain waste	Heat from peach chain waste
Total	Total	Pt	0,000523519	0,000495072	1,82E-05	1,02E-05
Human health	Carcinogens	Pt	6,22E-06	5,97E-06	1,42E-07	1,05E-07
	Non-carcinogens	Pt	6,80E-06	5,78E-06	3,02E-07	7,22E-07
	Respiratory inorganics	Pt	6,65E-05	5,63E-05	6,37E-06	3,86E-06
	Ionizing radiation	Pt	4,15E-07	3,95E-07	1,71E-08	3,49E-09
	Ozone layer depletion	Pt	7,72E-08	7,55E-08	1,41E-09	2,81E-10
	Respiratory organics	Pt	1,18E-07	1,12E-07	3,63E-09	1,73E-09
	Carcinogens in food product	Pt	0	0	0	0
	Fabbisognocaloricorecuperabile	Pt	7,59E-09	7,47E-09	1,09E-10	1,77E-11
	Non-carcinogens in food product	Pt	2,17E-12	2,13E-12	3,82E-14	6,40E-15
Ecosystem quality	Aquatic ecotoxicity	Pt	1,20E-05	1,17E-05	2,21E-07	8,13E-08
	Terrestrial ecotoxicity	Pt	3,56E-06	2,00E-07	6,16E-07	2,74E-06
	Terrestrial acid/nutri	Pt	1,60E-06	1,12E-06	3,68E-07	1,18E-07
	Land occupation	Pt	0,00023049	0,000225692	4,12E-06	6,81E-07
Climate change	Global warming	Pt	9,44E-05	8,94E-05	3,72E-06	1,26E-06
Resources	Non-renewable energy	Pt	0,00010106	9,81E-05	2,32E-06	6,64E-07
	Mineral extraction	Pt	2,80E-07	2,69E-07	8,01E-09	2,11E-09

As far as damage categories are regarded, the main category is **Ecosystem Quality**, which causes 0,000247618 Ptof damage, equal to a 47,30% share. The most important substances are, also in this case, related to **Land occupation** (*Transformation, to arable, non irrigated*and*Transformation, to permanent crop, fruit*). **Resources** consumption, with a score of 0,00010134 Pt, contributes for the 19,35% to the total damage, in particular because of the extraction of *Gas, natural, in ground* and*Oil, crude, in ground*, used in the production of **Non-renewable energy**. The third category is **Climate change**, which has a total score of 9,43822E-05 Pt, causing a

18,03% share, mainly related to the emission of *Carbon Dioxide, fossil* in air. Finally, **Human Health** determines a relatively small share, equal to the 15,32% with a score of 8,0179E-05 Pt, determined mainly by the emissions of *Nitrogen oxide*, *Particulates <2,5 um*,and*Sulfur Dioxide* in air, which are particularly relevant for **Respiratory inorganics**.

As far as single processes are regarded, in the case of <u>Peach nectar, consumed at house (coproduct) (not integrated)</u>, the total damage is equal to 0,000495 Pt. It must be noted that this score is 5% lower than the impact caused by the conventional chain (0,000517 Pt)and that, therefore, a 5% of the agro-food chain damage is allocated on waste and byproducts. In this process, most of the damage (48,21%) is in the category **Ecosystem Quality**, mainly because of land use, while another 38% is due to Non-renewable energy and Climate change impacts. Finally, only the 13,87% is related to the impact on**Human Health.**

In the case of <u>Electricity from peach chain waste</u>, the damage is substantially lower, amounting at 6,83553E-06 Pt. Most of this score, the37,55%, is caused by**Human Health**impact: in fact, as observed also in the integrated scenarios, the cogeneration of electricity, in particular from biogas anaerobic digestion, leads to an increase in the emission of *Ammonia* in air.The **Ecosystem Quality** category accounts for the 29,24%, and most of this damage derives from the land used in the production of feestock. In fact, the most relevant substance is represented by *Transformation, to arable, non irrigated*, which represents the land occupation of maize used for starch production. The third category is **Climate change**, which represents one fifth of the total damage (20,42%) mostly caused by the emission of *Carbon Dioxide, fossil* in air deriving from the fossil-based energy (electricity and heat) usedin the feedstock production (the nectar chain), and by the emission of *Dinitrogen monoxide* in air during the anaerobic digestion of agro-food waste. Finally, the **Resources** consumption represents only the12,79%, again related to the feedstock and its previous "history": in fact, the most relevant substance is *Gas, natural, in ground*, extracted to produce both electricity and heat**.**

Finally, in the case of <u>Heat from peach chain waste</u>, the total score is 4,69178E-06 Pt. Also in this process, most of the damage (45,80%) is linked to the**Human Health**impact of some emissions of energy production processes. In particular, a crucial substance is the*Particulates <2,5 um* in air, caused by the heat generated during prunings co-combustion. This process causes also another relevant share of damage through the emission of *Aluminium* in soil, deriving from the end-of-life treatment of prunings combustion ashes. In fact this emission determines most of the 35,36% related to **Ecosystem Quality**.The **Climate change** impact of heat production is quite limited, representing only the 12,33% of the total damage. Most of this is due to the emission of *Dinitrogen monoxide* in air during the combustion of prunings and the anaerobic digestion of peach wastes. Nevertheless, there is also some influence related to the emission of *Carbon Dioxide, fossil* in air, deriving from the diesel consumed in the processes.Finally, the **Resources**consumption account only for the 6,51% of the total and is mostly related to the indirect consumption of *Oil, crude, in ground*and*Gas, natural, in ground*in the processes of extraction of fossil fuels for power and heat production**.**

In general, it is possible to argue that, while the agro-food chain process presents similar impact compared to the conventional chain, with the exception of allocation of the damage on prunings and peach wastes, the bioenergy production processes add a further limited but relevant share of impacts. These impacts are, for a large share, deriving from the processes of cogeneration of electricity and heat, and, for a minimal part, from the same co-produced wastes. Furthermore, the damage attributable to these processes, despite its limited extent, are morerelated to **Human health**, than to **Ecosystem quality**.

In the following paragraphs, these first insights are furhter deepened through a comparison of the not integrated system with the previously analyzed scenarios, and through the comparison of electricity and heat from peach chain waste with the "conventional" electricity and heat. These comparisons should be useful to show the main changes in the life cycle environmental impact, which are directly imputable to the energetic recovery of waste, but without the hypothesis of self-consumption.

6.2 Comparison with the conventional and integratedbioenergy chains

In order to compare the "not integrated" scenario with the conventional chains, the following processes have been confronted, using IMPACT 2002+ 240412 (catena alimentare) V 2.10 (Chap. 3):

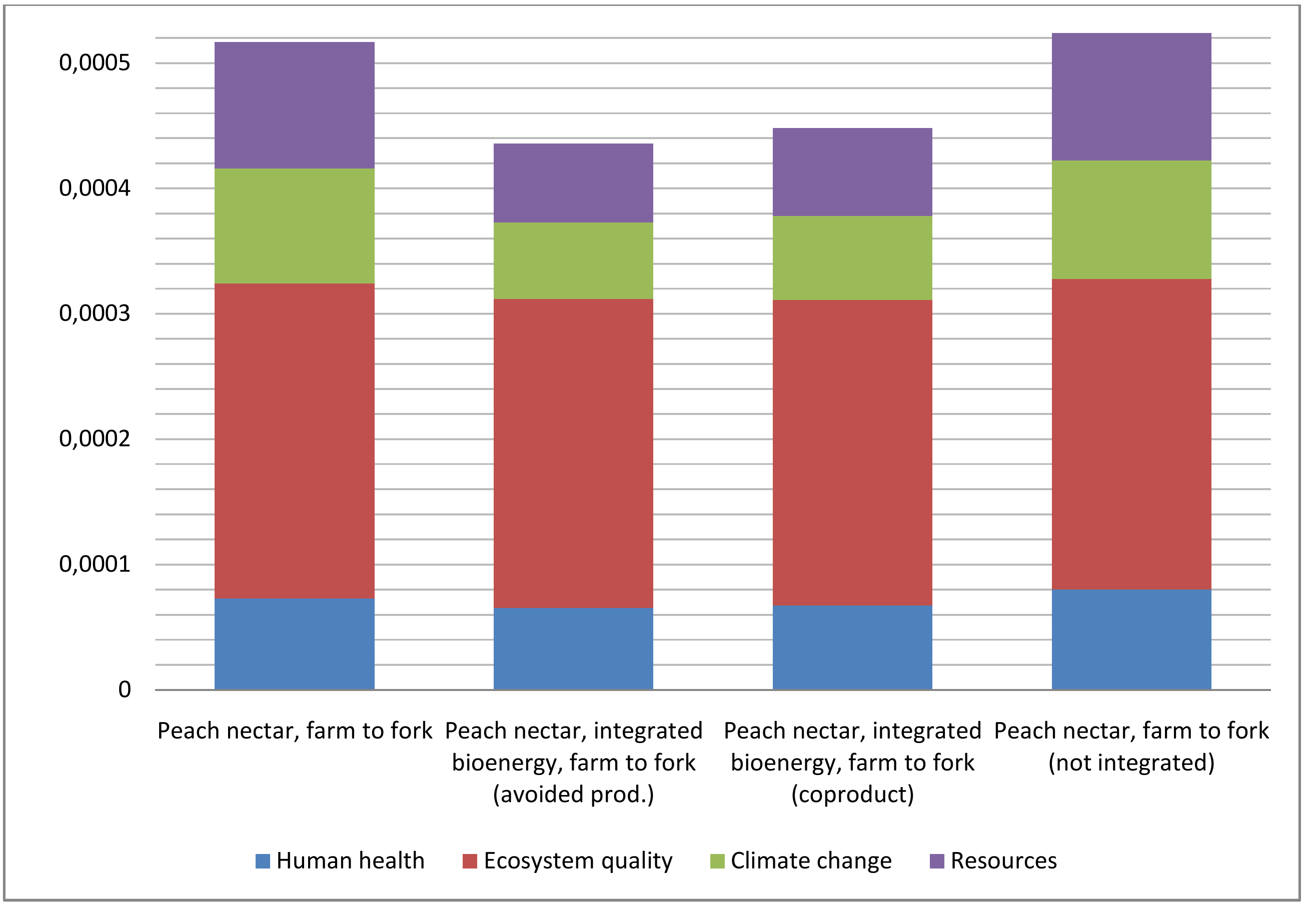
- The process representing the conventional chain, Peach nectar, farm to fork (Chap. 4);
- The processes that represents the integrated bionenergy scenario: Peach nectar, integrated bioenergy, farm to fork (avoided prod.)and Peach nectar, integrated bioenergy, farm to fork (coproduct.) (Chap. 5);
- The processe analyzed in the previous paragraph: Peach nectar, farm to fork (not integrated).

In this comparative analysis, it has been preferred to highlight the main consequences of the absence of energy self-consumption by focusing on the results of the comparison in terms of weighting per single score, with the mentioned method. Results in absolute terms per process and per impact category are presented in Tab. 6.2, while in Fig. 6.2 it is represented the diagram of weighting per damage category and inTab. 6.3 variations of weighting per single score and damage category in the not integrated scenariothe variation between the “not integrated” scenario and the others are listed in percentage terms.

Tab. 6.2The weighting per single score with IMPACT of the comparison between the processesPeach nectar, farm to fork, Peach nectar, integrated bioenergy, farm to fork (avoided prod.), Peach nectar, integrated bioenergy, farm to fork (coproduct) e Peach nectar, farm to fork (not integrated)

Damage category	**Impact category**	**Unit**	**Peach nectar, farm to fork**	**Peach nectar, integrated bioenergy, farm to fork (avoided prod.)**	**Peach nectar, integrated bioenergy, farm to fork (coproduct)**	**Peach nectar, farm to fork (not integrated)**
Total	Total	Pt	0,000516741	0,000435481	0,000447834	0,000523519
Human health	Carcinogens	Pt	6,25E-06	5,38E-06	5,52E-06	6,22E-06
	Non-carcinogens	Pt	7,86E-06	6,60E-06	6,57E-06	6,80E-06
	Respiratory inorganics	Pt	5,81E-05	5,31E-05	5,48E-05	6,65E-05
	Ionizing radiation	Pt	4,03E-07	3,22E-07	3,33E-07	4,15E-07
	Ozone layer depletion	Pt	7,72E-08	7,13E-08	7,18E-08	7,72E-08
	Respiratory organics	Pt	1,15E-07	9,88E-08	1,02E-07	1,18E-07
	Carcinogens in food product	Pt	0	0	0	0
	Recoverable food calories	Pt	7,60E-09	7,60E-09	7,56E-09	7,59E-09
	Non-carcinogens in food product	Pt	2,17E-12	2,17E-12	2,15E-12	2,17E-12
Ecosystem quality	Aquatic ecotoxicity	Pt	1,19E-05	1,19E-05	1,18E-05	1,20E-05
	Terrestrial ecotoxicity	Pt	7,81E-06	2,33E-06	2,34E-06	3,56E-06
	Terrestrial acid/nutri	Pt	1,17E-06	1,38E-06	1,41E-06	1,60E-06
	Land occupation	Pt	0,000230428	0,000230402	0,00022819	0,00023049
Climate change	Global warming	Pt	9,19E-05	6,10E-05	6,69E-05	9,44E-05
Resources	Non-renewable energy	Pt	0,000100457	6,26E-05	6,95E-05	0,00010106
	Mineral extraction	Pt	2,75E-07	2,42E-07	2,45E-07	2,80E-07

Fig. 6.2Diagram of the weighting per single score with impact of the comparison between the processes<u>Peach nectar, farm to fork</u>, <u>Peach nectar, integrated bioenergy, farm to fork (avoided prod.)</u>, <u>Peach nectar, integrated bioenergy, farm to fork (coproduct)</u>, e <u>Peach nectar, farm to fork (not integrated)</u>



Tab. 6.3 variations of weighting per single score and damage category in the not integrated scenario

	Non integrato			
Category	**Pt**	**Var. from conventional (%)**	**Var. from avoided prod. (%)**	**Var. from co-products (%)**
Human health	8,0179E-05	10,12	22,19	18,96
Ecosystem quality	0,000247618	-1,48	0,64	1,58
Climate change	9,43822E-05	2,76	54,68	41,07
Resources	0,00010134	0,60	61,38	45,25
Total	**0,000523519**	**1,31**	**20,22**	**16,90**

From these data it is possible to highlight some relevant trends. First of all, as expected, the “not integrated” scenario has the highest impact with a single score equal to 0,000523519 Pt. The end-of-life of food waste chain in respect to the conventional chain causes an overall 1,31%increment, which is likely to represent the effect of cogeneration processes, net of the reductionof the emissions caused by composting. The damage difference is higher, when the “not integrated” scenario is compared to the integrated bioenergy chain: in particular, the score is respectively the 20,22% and the 16,9% higher than the “avoided products” and “co-products” scenarios. In this case, the increase is likely to derive from the absence of self-consumption and fossil-based energy substitution.

As far as damage categories are regarded, with the exclusion of **Ecosystem quality**, the “not integrated” chain is characterized by the higher damage in all the categories. In the specific, in **Human Health**the impact results to be very high, with a 10,12% increasecompared to the conventional chain and a 22,19% and 18,96% in respect to “avoided products” and “co-products”. This increase can be explained by looking at the modification in the impacts of single substances. Most of the damage increase is related to *Nitrogen oxides*, *Particulates, < 2.5 um*, *Sulfur dioxide*,and *Ammonia*(Tab. 6.4 Specification per substance of the damage in Human Health (1st 10 substance per value with reference to the conventional)).

Tab. 6.4 Specification per substance of the damage in Human Health (1st 10 substance per value with reference to the conventional)

No	Substance	Compart.	Conventional	Avoided prod.	Co-products	Not integrated
	Total		7,2808E-05	6,5618E-05	6,7399E-05	8,0179E-05
1	Nitrogen oxides	Air	2,2516E-05	1,9116E-05	1,9851E-05	2,4414E-05
2	Particulates, < 2.5 um	Air	1,2654E-05	1,2253E-05	1,2477E-05	1,4450E-05
3	Sulfur dioxide	Air	1,1593E-05	7,9600E-06	8,5528E-06	1,2324E-05
4	Hydrocarbons, aromatic	Air	4,8072E-06	4,1082E-06	4,2425E-06	4,8335E-06
5	Particulates, > 2.5 um, and < 10um	Air	4,5103E-06	4,1903E-06	4,2230E-06	4,6666E-06
6	Particulates, > 10 um	Air	3,5099E-06	2,5558E-06	2,6859E-06	3,5870E-06
7	Ammonia	Air	3,2056E-06	7,0607E-06	7,0019E-06	7,0903E-06
8	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	Air	2,6482E-06	2,7534E-06	2,7503E-06	2,8186E-06
9	Cadmium	Soil	1,5771E-06	1,5770E-06	1,5617E-06	1,5770E-06
10	Arsenic	Soil	1,5594E-06	2,7808E-07	2,7847E-07	2,9492E-07

As already mentioned, **Ecosystem quality**is the only category where the “not integrated” produces a reduced damage in comparison wiith the conventional chain, which as the higher score. This slight reduction (1,48%) is mainly due to the lower emission of *Zinc* in soil, given that biowaste is not used anymore for the production of compost (Tab. 6.5Specification per substance of the damage in Ecosystem quality (1st 10 substance per value with reference to the conventional)). It must be noted, that, for the same reason, in this category, the damage of the “not integrated” system is comparable or slightly higher than the integrated bioenergy scenarios. Therefore, it is possible to argue that, regardless of the aim of bioenergy generation, there is a reduction of the potential heavy metal emission in soil, which is deriving from the composting processes. At the same time, as already argued, this effect is regarded as “positive” from the chosen analysis method, and the data regarding heavy metal content in plant parts can not be considered entirely certain.

Tab. 6.5Specification per substance of the damage in Ecosystem quality (1st 10 substance per value with reference to the conventional)

No	Substance	Comp.	Conventional	Avoided prod.	Co-products	Not integrated
	Total		0,00025135	0,00024605	0,000243763	0,000247618
1	Transformation, to arable, non-irrigated	Raw	0,000169756	0,000169767	0,000168123	0,000169754
2	Transformation, to permanent crop, fruit	Raw	7,48E-05	7,48E-05	7,41E-05	7,48E-05
3	Fluvalinate	Water	1,07E-05	1,07E-05	1,06E-05	1,07E-05
4	Zinc	Soil	4,10E-06	-1,67E-08	-2,04E-09	3,77E-08
5	Occupation, forest, intensive	Raw	3,53E-06	3,53E-06	3,50E-06	3,53E-06
6	Occupation, arable, non-irrigated	Raw	3,33E-06	3,33E-06	3,29E-06	3,33E-06
7	Aluminium	Soil	1,44E-06	2,77E-06	2,82E-06	3,18E-06
8	Aluminium	Air	1,17E-06	7,91E-07	8,33E-07	1,19E-06
9	Nitrogen oxides	Air	7,47E-07	6,34E-07	6,58E-07	8,10E-07
10	Cadmium	Soil	7,07E-07	6,82E-07	6,75E-07	6,82E-07

In **Climate change**, the damage produced by “not integrated” chain is the highest, in particular when compared to the integrated bioenergy scenario. In fact, in this system there isn’t a decrease of fossil energy consumption, and at the same time, there are the emissions connected to bioenergy production. Thus, most of the difference is determinedby the emission of *Carbon dioxide, fossil origin* in air, which is particularly low in the case of “avoided products” and “co-products”, where it compensates also the increase in the emission of *Dinitrogenmodoxide* in air, caused by bioenergy production (Tab. 6.6).

Tab. 6.6Specification per substance of the damage in Climate change (1st 7 substance per value with reference to the conventional)

No	Substance	Comp.	Conventional	Avoided prod.	Co-products	Not integrated
	Total		9,19E-05	6,10E-05	6,69E-05	9,44E-05
1	Carbon dioxide, fossil	Air	8,34E-05	5,12E-05	5,70E-05	8,37E-05
2	Dinitrogen monoxide	Air	5,41E-06	7,40E-06	7,34E-06	7,50E-06
3	Methane, fossil	Air	1,75E-06	1,06E-06	1,21E-06	1,75E-06
4	Methane, tetrafluoro-, CFC-14	Air	5,96E-07	5,94E-07	5,89E-07	5,97E-07
5	Carbon monoxide, fossil	Air	2,24E-07	2,13E-07	2,14E-07	2,27E-07
6	Methane, biogenic	Air	1,50E-07	2,84E-07	2,82E-07	2,89E-07
7	Sulfur hexafluoride	Air	1,40E-07	6,73E-08	7,67E-08	1,41E-07

Similarly, in **Resources** category, the “not integrated” scenario has the worst performance, with a score slightly higher than the conventional chain, because of the increased use of electricity from network, buta larger difference with the integrated bioenergy scenario, which is enterile deriving from the absence of self-consumption (Tab. 6.7).

Tab. 6.7Specification per substance of the damage in Resources (1st 5 substance per value with reference to the conventional)

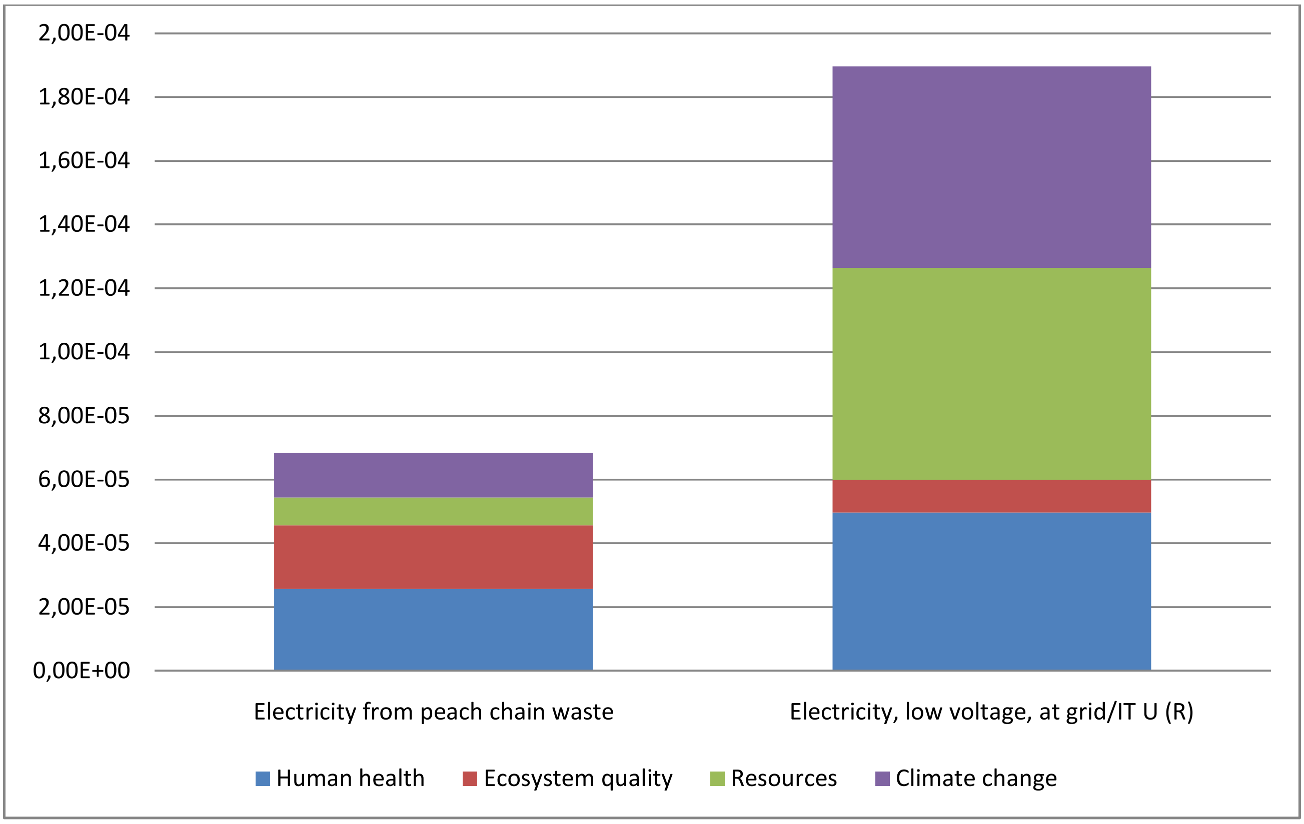
No	Substance	Conventional	Avoided prod.	Co-products	Not integrated
	Total	0,000100733	6,28E-05	6,98E-05	0,00010134
1	Gas, natural, in ground	5,68E-05	2,63E-05	3,24E-05	5,67E-05
2	Oil, crude, in ground	2,59E-05	2,30E-05	2,33E-05	2,62E-05
3	Uranium, in ground	9,10E-06	7,43E-06	7,66E-06	9,37E-06
4	Coal, hard, unspecified, in ground	6,87E-06	4,27E-06	4,63E-06	6,97E-06
5	Coal, brown, in ground	1,66E-06	1,37E-06	1,41E-06	1,70E-06

6.3 Comparison between bioenergy from food waste and conventional energy

6.3.1 Comparison between electricity from network and electricity from peach chain waste

As showed in the previous paragraph, the agro-energetic system presents an increase of the damage which is mainly linked to the cogeneration of bioenergy from peach chain waste. As already argued, this energies have been included as further processes in that system only to underline the main differences with the scenario where self-generation and consumption is assumed. However, in a traditional approach, these energies, and the related impact, should be attributed to the system in which they are actually consumed. Therefore, it seems relevant to compare also these renewable energies produced (both the electricity and heat) with the largely fossil-based energy used in the conventional chain. In this paragraph it is presented the comparative analysis of the weighting per single score of the processes Electricity from peach chain wasteandElectricity, low, voltage, at grid/IT per a functional unit analyzed of 1 kWh. The results of this comparison are presented in Fig. 6.3 Diagram of the weighting per single score of the processes Electricity from peach chain wasteandElectricity, low, voltage, at grid/IT and in Tab. 6.8.

Fig. 6.3 Diagram of the weighting per single score of the processes <u>Electricity from peach chain waste</u>and<u>Electricity, low, voltage, at grid/IT</u>



It is important to note that the first process represents a weighted average of the various electricity forms produced from each chain waste of single segments. This implies that the damage of single electricity forms is different, both for the technology used (for example between cultivation and the other segments), and for the feedstock (prunings vs. peach wastes vs. nectar wasted). Furthermore, given that each segment of the nectar chain is constituted by a multioutput process, the damage associated to each waste co-produced, and thus attributed to bioenergy production, increases at each segment.

Tab. 6.8The weighting per single score with IMPACT of the comparison between the processes<u>Electricity from peach chain waste</u> e <u>Electricity, low, voltage, at grid/IT</u>

Damage category	Impact category	Unit	Electricity from peach chain waste	Electricity, low voltage, at grid/IT U (R)	Var %
Total	Total	Pt	6,83892E-05	0,000189647	-63,93866

Human health	Carcinogens	Pt	5,34132E-07	7,90826E-07	-32,45902
	Non-carcinogens	Pt	1,13333E-06	1,2184E-06	-6,98196
	Respiratory inorganics	Pt	2,3931E-05	4,7244E-05	-49,34598
	Ionizing radiation	Pt	6,4248E-08	3,60859E-07	-82,19585
	Ozone layer depletion	Pt	5,31038E-09	8,32704E-09	-36,22728
	Respiratory organics	Pt	1,36429E-08	3,71837E-08	-63,30938
	Carcinogens in food product	Pt	0	0	-
	Recoverable food calories	Pt	4,07694E-10	0	-
	Non-carcinogens in food product	Pt	1,43655E-13	0	-
Ecosystem quality	Aquatic ecotoxicity	Pt	8,3013E-07	1,60661E-07	416,6968
	Terrestrial ecotoxicity	Pt	2,31321E-06	9,0811E-06	-74,52724
	Terrestrial acid/nutri	Pt	1,38267E-06	7,15456E-07	93,25771
	Land occupation	Pt	1,54678E-05	3,24214E-07	4670,872
Climate change	Global warming	Pt	1,39641E-05	6,3157E-05	-77,88988
Resources	Non-renewable energy	Pt	8,71908E-06	6,63934E-05	-86,86756
	Mineral extraction	Pt	3,0089E-08	1,55283E-07	-80,62307

From these data, it is possible to note how the process representing the electricity produced from peach chain waste produces a damage which is the 63,94% lower than the damage caused by the electricity from the national grid. The higher reduction, in both absolute and relative terms, is located in the categories **Resources** (-86,85%) and**Climate change** (-77,88%). In fact, these are the damage categories with the highest impact in the case of conventional electricity: together they represent about the 70% of the total damage. On the contrary, in the category**Ecosystem quality**, which represents the 5% of the total impact of networkk electricity, the damage caused by peach chain waste electricity is about twice, and it represents almost one third of the overall impact produced by 1 kWh (Tab. 6.9).

Tab. 6.9 Percentage change of the damage from peach chain waste electricity compared to electricity from network

Damage category	1) Electricity from peach chain waste	2) Electricity, low voltage, at grid/IT U (R)	Var. of 1 from 2 (%)
Total	6,84E-05	0,000189647	-63,93866
Resources	8,75E-06	6,65E-05	-86,85298
Climatechange	1,40E-05	6,32E-05	-77,88988
Human health	2,57E-05	4,97E-05	-48,2838
Ecosystem quality	2,00E-05	1,03E-05	94,46537

As far as impact categories are regarded, it is possible to underline how in almost every **Human health** category the damage caused by the electricity from peach chain waste is lower, in particular in the case of **Respiratory inorganics**, mainly because of the reduced emissions of *Nitrogen oxides*and*Sulfur dioxide* in air. It must be noted, however, that the same process produces some damages in the categories**Recoverable food calories**and**Non-carcinogens in food products**: in both these categories this is the result of the use of feedstock coming from the food chain, which have been considered as co-products and thus present a share of the impacts of their origin.

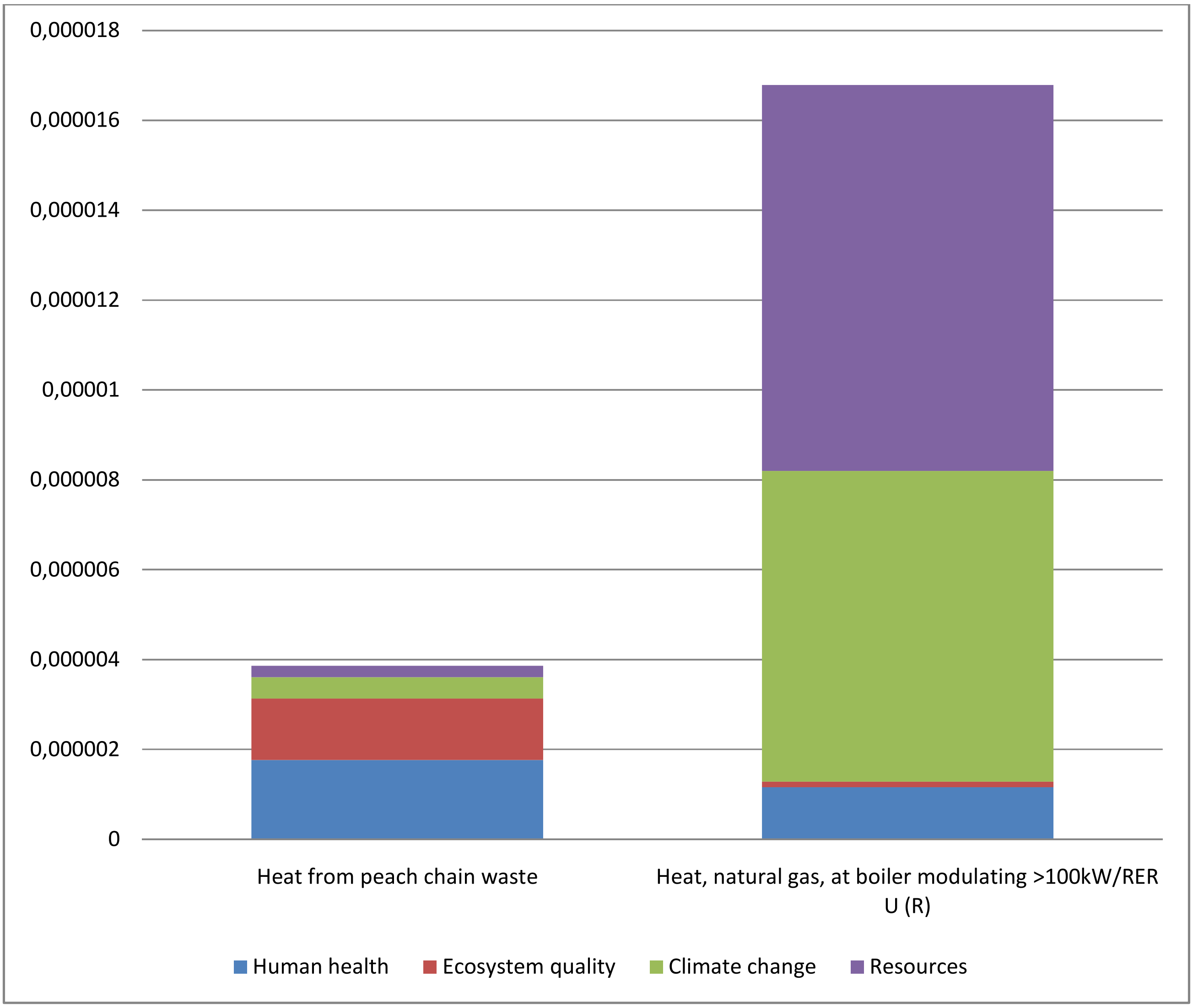
Among the impact categories classified under **Ecosystem quality**, the higher damage caused by the electricity from peach chain waste is attributable to **Land occupation**, with a value that is 47 times larger than the score of electricity from network. Also in this case, through a specification per substances, the main factor is the feedstock used: in fact, the more relevant substances are Transformation, to arable, non irrigated (due in a large part to green manure needed for the maize used for the production of glucose from starch and for sugar beet) andTransformation, to permanent crop, fruit (due to cultivation of peaches). Furthermore, this increase compensate also the damage reduction associated to the lower need of land for fossil fuel extraction (Transformation, to mineral extraction site). Another important share of damage is imputable to the categories**Terrestrial acid/nutri**, in which an increase of Ammonia in air emissionsfrom anaerobic digestion can be registered, and **Aquatic ecotoxicity**, in which the huge difference with the conventional electricity is in a large parte determined by the emission of *Fluvalinate* in water, during the cultivation of peaches. These damages are only partially compensated by the lower impact in the category**Terrestrial ecotoxicity**, thanks to the reduced emission of *Copper* in soil, mostly associated to the process Distribution network, electricity, low voltage.

6.3.2 Comparison between heat from natural gas and heat from peach chain waste

In this paragraph it is presented the comparative analysis of the weighting per single score of the processes Heat from peach chain wasteandHeat, natural gas, at boiler modulating >100kW/RER per a functional unit analyzed of 1 MJ. The results of this comparison are presented in Fig. 6.4 and inTab. 6.10. As in the case of electricity, also in the case of heat, the first process represented is constituted by the weighted average of the various heat forms produced from each chain waste of the single segments. In the specific, in each segment, heat represents the other co-product of cogeneration processes.

In general, it is possible to argue that the process representing the heat from peach nectar chain waste produces a lower damage if compared to the conventional gas-based heat. The reduction can be quantified in a 77% (Tab. 6.10). The impact is particularly lower in the categories **Resources** (-97%) and **Climate change** (-93%), which are the most damaging categories in the case of natural gas heat, determining together about the 87% of the total). On the contrary, in the category **Human health**, which represent only the 7% of the total damage of the natural gas heat, there is a major increase (42%), so that this category is equal to the 45% of the total damage of the heat from peach chain waste. Finally, in the category **Ecosystem quality**, which represents only the 0,76% of the total damage in the case of natural gas heat, the damage caused by heat from peach chain waste is around 11 times higher, determining about the 35% of the total.

Fig. 6.4Diagram of the weighting per single score with IMPACT of the comparison between the processes Heat from peach chain waste e Heat, natural gas, at boiler modulating >100kW/RER



Tab. 6.10Percentage change of the damage from peach chain waste heat compared to heat from network

Damage category	1) Heat from peach chain waste	2) Heat, natural gas, at boiler modulating >100kW/RER U (R)	var % 1 rispetto a 2
Total	3,85685E-06	1,67864E-05	-77,024
Human health	1,76634E-06	1,15845E-06	52,47388
Ecosystem quality	1,36396E-06	1,28056E-07	965,1274
Climate change	4,75591E-07	6,91806E-06	-93,1254
Resources	2,50952E-07	8,58184E-06	-97,0758

Hereafter, the differences in each impact category are listed (Tab. 6.11). It is possible to underline how in the impact categories that are related to **Human health**, there is a higher damage in the case of peach chain waste heat, in particular in the case of **Respiratory inorganics**, mostly because of the higher emissions of *Particulates, <2,5um*and *Ammonia* in air, caused by the combustion of prunings and by the digestion of wet wastes. Furthermore, it must be noted how the bio-heat determines an higher damage in the case of **Non-carcinogens**, mainly because of the *Zinc*emission in soil, determined by the end of life of combustion ashes.

Tab. 6.11The weighting per single score with IMPACT of the comparison between the processesHeat from peach chain wasteandHeat, natural gas, at boiler modulating >100kW/RER

Damage category	Impact category	Unit	1) Heat from peach chain waste	2) Heat, natural gas, at boiler modulating >100kW/RER U (R)	Var % da 1 a 2
Total	Total	Pt	3,86E-06	1,68E-05	-77,024
Human health	Carcinogens	Pt	3,94E-08	2,55E-07	-84,5714
	Non-carcinogens	Pt	2,72E-07	1,83E-08	1387,757
	Respiratory inorganics	Pt	1,45E-06	8,78E-07	65,58524
	Ionizing radiation	Pt	1,31E-09	2,22E-09	-40,7786
	Ozone layer depletion	Pt	1,06E-10	1,51E-09	-92,9876
	Respiratory organics	Pt	6,53E-10	3,77E-09	-82,6942
	Carcinogens in food product	Pt	0	0	-
	Recoverable food calories	Pt	6,66E-12	0	-
	Non-carcinogens in food product	Pt	2,41E-15	0	-
Ecosystem quality	Aquatic ecotoxicity	Pt	3,06E-08	2,39E-09	1182,024
	Terrestrial ecotoxicity	Pt	1,03E-06	9,19E-08	1023,542
	Terrestrial acid/nutri	Pt	4,44E-08	1,93E-08	129,6307
	Land occupation	Pt	2,56E-07	1,44E-08	1675,54
Climate change	Global warming	Pt	4,76E-07	6,92E-06	-93,1254
Resources	Non-renewable energy	Pt	2,50E-07	8,58E-06	-97,0848
	Mineral extraction	Pt	7,93E-10	6,12E-10	29,46518

As in the case of electricity from peach chain waste, also the heat provokes damages in the categories **Recoverable food calories**and **Non-carcinogens in food product**. The only sensible reduction related to **Human Health** can be found in **Carcinogens**, which can be attributed to the lower emission of *Hydrocarbons, aromatic* in air, usually related to the extraction of natural gas.

In the impact categories related to **Ecosystem quality**, the higher damage caused by heat from peach chain waste is attributable partly to **Land occupation**, and for a larger share to **Terrestrial ecotoxicity**, mostly because of the emissions of *Zinc*and*Aluminium* in soil, which are related to the management of ashes deriving from prunings combustion. Furthermore, as in the case of electricity from peach chain waste, a further share of damage derivese from the categories**Terrestrial acid/nutri**, in which an increase of the emission of *Ammonia* in air, deriving from the anaerobic digestion of waste, can be registered, and**Aquatic ecotoxicity**, where the 1182% increase is largerly due to the emission of *Aluminium* in soiland*Fluvalinate* in water. Finally, the larger reduction in absolute terms are in the categories **Global warming**and**Non-renewable energy**.

7 Conclusions

8 References

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