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Transportation Research Procedia 67 (2022) 83–92

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th International Conference on Food and Wine Supply Chain

Implication of SDGs on LCA based sustainable design of milk powder's dairy production

Valeria Fois[a*], Daniele Cocco[a]

DIMCM -Dept. of Mechanical, Chemical and Materials Engineering, , University of Cagliari, Via marengo 2, 09123, Cagliari,Italy

Abstract

The Sustainable Development Goals (SDGs) of the United Nations (UN) 2030 Agenda are challenging targets that can drive productions processes to improve their environmental performance. This paper proposes a new methodology, based on a LCA approach in Food Supply Chain to support managers in the decision-making process with the goal to address complex sustainability challenges. As case-study, this goal-oriented design methodology is applied to the design process of a milk powder factory to be established in Sardinia. In this study, 5 SDGs indicated by the UN 2030 Agenda have been selected and the effect of different design options on their achievement has been evaluated by using the weights resulting from a specific LCA assessment. Different supply chains in terms of feedstocks (sheep milk and wheat) and energy supply options (photovoltaic, wind turbines and Combined Heat and Power plants) are considered and compared. The results demonstrate that the proposed SDG-oriented design method can be a useful tool to drive design choices towards more sustainable food production systems and operations.

Keywords: Sustainable; LCA; Milk Powder; Renewable Energy;

* Corresponding author e-mail address: valeria.fois@unica.it

10.1016/j.trpro.2022.12.038

1. Introduction

Six years ago, the United Nations Sustainable Development Goals (SDGs) set an ambitious target to achieve a sustainable and fair future for people worldwide by 2030 (United Nations, 2015). The global community has agreed on 17 Sustainable Development Goals (SDGs) to address various global development challenges and inequalities. The SDGs provide a framework to include social and environmental sustainability in development processes. Innovative, clean, and sustainable technologies are crucial instruments for advancing towards these SDGs. Supportive technology policy is therefore of paramount importance to stimulate the development and diffusion of those technologies. Most countries have adopted the SDGs into their development agendas, and by 2019, 144 countries have presented their voluntary national reviews on SDGs at the UN's High-level Political Forum (Shariatzadeh et Al., 2016). Making development sustainable is in general a challenging and complex undertaking, involving such factors as technology and engineering, economics, environmental stewardship, health and welfare of people and the communities in which they live and work, social desires, and government strategies, procedures and policies (Santika et Al., 2020). An important example is the use of renewable energy sources (RES) for achieving SDG #7 ("Ensure access to affordable, reliable, sustainable and modern energy for all"). Thus, many international institutions and national governments promote RES for the energy transition and rural electrification to provide and improve energy access and to address increasing energy demands in a sustainable manner (Bertheau, 2020).

With reference to production processes, energy and the application of new technologies are the key factors for ensuring competitiveness and improve sustainability and one of the most energy intensive sectors is the agri-food industry with its large use of electrical, thermal and cold energy. In particular, the dairy industry in Italy is responsible for 15% of the total energy demand in the food sector, because dairies require large amounts of energy for their heating and cooling processes. In particular, dehydration processes for the production of milk powder (about 35% whole and 65% skimmed milk powder, Eurostat 2015) require significant amounts of thermal energy. Evaporation and spray drying are responsible for about 96% of the total energy used for milk powder production. To reduce the energy consumption, emerging processing technologies and alternative energy supply systems need to be investigated for milk powder production. In particular, emerging technologies can reduce the energy consumption up to 60% in milk powder production (Moejes and van Boxtel, 2017). Similarly, the overall supply chain of milk powder farms can be optimized to reduce energy consumptions and environmental emissions.

As well known, one of the most useful tools for the improvement of the environmental performance of products and services is Life Cycle Analysis (LCA). With reference to the agri-food sector, many international studies demonstrate that LCA is a relevant approach to improve the environmental performance of agri-food processes, especially for Small – and Medium -sized Enterprise (SMEs). For instance, the study of Arzoumanidis et al. (2017) focuses on the implementation of LCA tools for the production processes of roasted coffee, lemon juice, olive oil, and wine. The analysis carried out highlight some general improvements that could be advantageous for agri-food products. Vagnoni et al. (2017) define a preliminary characterization of the environmental profile of sheep milk cheese chain in Sardinia (Italy) and compare the environmental impact caused by artisanal and industrial manufacturing processes of "Pecorino" cheese and identify the hotspot to reduce the environmental impacts of the Sardinian dairy sheep sector. Yan and Holden (2018) use LCA applied to three dairy's products to find the major contributors to energy use and greenhouse gas emission, to understand the variation of environmental impacts and to identify the scope for improvement. Cumulative energy demand and carbon footprint of butter, skimmed milk powder and fat filled powder were calculated. In addition, the study of Depping et al. (2020) offers a systematic procedure to deal with multi-product processes in life cycle assessment that is useful for a wide range of applications. Gésan-Guiziou et al. (2019) found that for reducing the overall environmental impact of the milk protein fractionation process it is advisable to primary focus on improvement and optimization of the microfiltration operation and thermal processes. The results show that the production phase accounts for approximately two-thirds of the environmental impacts of the entire food manufacturing process, and that the cleaning phase for more than 30% of the total impact.

Therefore, contribution to the targets set by the UN Sustainable Development Goals (SDGs) is gaining more and more importance in the feasibility analysis of new investments. In this regard, this paper proposes a new methodology to support managers in the decision-making process with the goal to address complex sustainability challenges. The proposed methodology, based on a network algorithm and on a LCA approach, analyses 5 of the SDGs included in the UN 2030 Agenda. The SDGs taken into consideration are: Affordable Clean Energy (SDG7), Create Decent Work and Economic Growth (SDG8), Increase Industry, Innovation, and Infrastructure (SDG9), Influence Responsible Consumption and Production (SDG12), Climate action (SDG13), Build Partnerships for the Goals (SDG17). The proposed method evaluates the effect of different supply chain options in terms of contribution to the SDGs, by using weights derived from LCA studies.

As case-study, this goal-oriented design methodology is applied to the design process of a milk powder's dairy factory in Sardinia. The new plant will be built in 2022-2023 to produce sheep's milk powder for Chinese Infant Formula and will have to comply with Nzeb criteria for building and process equipment. Different supply chains in terms of feedstocks (sheep milk and wheat) and energy supply options (photovoltaic, wind turbines and Combined Heat and Power plants) are considered and compared. The design method allows to assess how the different options contribute to the achievement of the 5 selected SDGs, thus providing advantages for business in terms of environmental impact and innovation.

2. Materials and methods

As mentioned, this paper aims to propose a new tool to support the decision-making process by including the sustainability factors considered by the SDGs. In particular, the proposed methodology investigates the connections between the impact environmental categories considered by LCA studies and a selected set of the UN 2030 Agenda SDGs. Connections between SDGs and impact categories are firstly analyzed through a network algorithm, which measures a node's ability to communicate directly with other nodes. The LCA approach is used to weigh the impact categories and give a metrics for the SDGs.

As case study, different options for the design of a milk powder's factory, based on the use of sheep milk or whey as feedstock and renewable or fossil fuel energy supply systems, have been considered and compared.

2.1. Choice of SDGs

With reference to the case-study considered, 5 SDGs within the United Nations Sustainable Development Goals have been selected. The goals that best adapt to the design of a new sustainable dairy factory are:

- **SDG#7** Affordable and clean Energy: ensure access to affordable, reliable, sustainable and modern energy for all.
- **SDG#8** Decent work and economy growth: promote sustained, inclusive sustainable economic growth, full and productive employment and decent work for all.
- **SDG#9** Industry, Innovation and Infrastructure: build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
- **SDG#12** Responsible Consumption and Production: ensure sustainable consumption and production patterns.
- **SDG#17** Partnership for the Goals: strengthen the means of implementation and revitalize the global partnership for sustainable development.

The contribution of the different design choices to the achievement of the 5 SDGs is measured by using the weights calculated through an LCA study.

2.2. Life cycle assessment

The LCA study has been structured in accordance with the LCA guidelines of the International Organization for Standardization (ISO): ISO 14040 (ISO, 2006a) and ISO14044 (ISO, 2006b). ISO 14040 and 14044 outline a general procedure and constitute one of the major attempts of harmonization among different studies. The method defined by ISO includes four main steps: goal and scope definition, inventory analysis, impact assessment and interpretation of results. Every step entails several choices, and each one could affect the results of the analysis. The LCA is now one of the leading methodologies for environmental metric and it will potentially become a powerful strategic management and decision-making tool to make our society more sustainable and resource-efficient. The main strength of this method is the system prospective that aims to avoid the "shifting of burdens" from one environmental impact to another and from one stage of production to another (Hellweg et al., 2014).

As a first step, a systematic search of scientific literature was carried out in order to find LCA studies evaluating the environmental impacts of dairy sector. The checked database was Scopus (www.scopus.com;), which was visited last time on May 2021. The search updates and integrates the systematic review published by Baldini et al. (2017). The considered LCA studies are related to milk powder production from dairy cattle farming systems. Studies regarding the processing of milk after farm production were retrieved. Only studies including an impact assessment with more than one LCA indicator and using a CML method for impact assessment are considered. The new method starts from the environmental indicators included in CML method and it is integrated with the social and economic indicators coming from the other methods used in the LCA methodology (BEES, Ecological Scarcity 2007, Eco-Indicator 99, EPS 2000, EDIP 2003, IPCC GWP100a), as shows by Table 1.

The results of the LCA studies included in the database have been analyzed by using a specific network algorithm. In particular, the concept of centrality is used to determine the most important node in a network in terms of ability to directly communicate with other nodes. The degree of simple centrality measures a node's ability to communicate directly with other nodes. Degree i in a simple network G is defined using the network A adjacence matrix:

$$k_i = \sum_{j=1}^{n} a_{ij} = (\boldsymbol{e}^T A)_i = (A\boldsymbol{e})_i \qquad (1)$$

where **e** is a vector = 1
a is matrix component
i,j = nodes
So in G network, the node *i* is more central than a node *j* if $k_i > k_j$.

The elements of Table 1, impacts categories and goals, and the mutual connections are considered as nodes of the network. Deriving the matrix of adjacence A allows to calculate the centrality of the nodes. Figure 1 with a chromatic scale shows the connection graph. The structure of the graph includes "nodes" and "edges". Each node represents an entity, and each edge represents a connection between two nodes. SDGs 7, 9 and 12 are the most able to communicate. Nodes 8 and 17 are the least explored in the literature of the dairy sector.

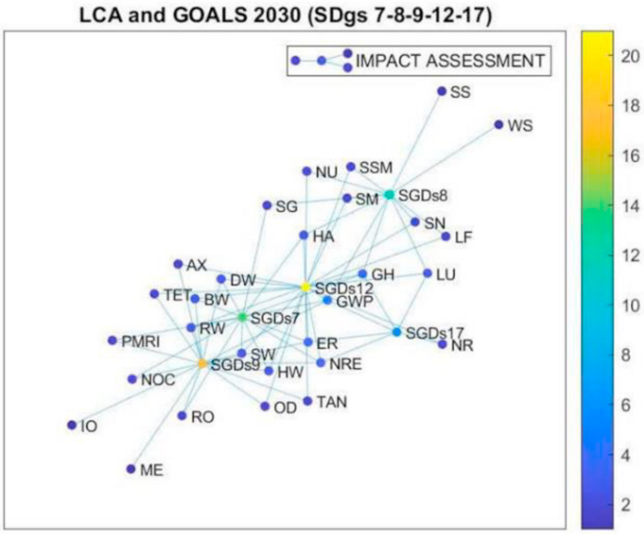

Fig. 1 Connections between impact categories and SDG.

Table 1. Considered SDGs and corresponding impact categories.

IMPACT	ENVIROMENTAL	SOCIAL	ECONOMIC
SDG#7:	Ozone layer depletion (OD)	Respiratory organics (RO)	Non-renewable energy (NRE)
NOC, RO, GWP, Sg, GH, NR, DW, PMRI, HA, NRE, HW, SW, BW. RW, ER	Non- carcinogens (NOC)	Ionizing radiation (IO)	Mineral extraction (ME)
	Respiratory inorganics (PMRI)	Habitat alteration (HA)	Hazardous waste (HW)
SDG#8:	Aquatic ecotoxicity (AX)	Life expectancy (LF)	Slags/ ashes (SW)
LU, GWP, Sg, WS, SS, GH.HA, LF, SSM, M, SN, NU	Terrestrial ecotoxicity (TET)	Severe morbidity and suffering (SSM)	Bulk waste (BW)
	Terrestrial acid/nutr (TAN)		Radiative waste (RW)
SDG#9:	Land occupation (LU)	Morbidity (M)	Renewable energy (RE)
OD, NOC, PMRI, AXTET, TAN, LU, NR, GH, IONRE, ME, HW, SW, BW, RW, RE	Global warming (GWP)	Severe nuisance (SN)	
	Smog (Sg)	Nuisance (NU)	
SDG#12:	Natural resourced (NR)		
OD, AX, TET, TAN, LU,GWP, NR, DW, GH, HA, LF, SSM, M, SN, NU, NRE, HW, SW, BW, RW,RE	Deposited waste (DW)		
	Winter smog (WS)		
	Summer smog (SS)		
SDG#17:	Greenhouse (GH)		
LU, GWP, NR, GH, NRE, RE			

3. Case Study

The proposed methodology to support design choices addressed to comply with the SDGs is based on a LCA approach. As case study, the method has been applied to Alimenta, a new factory for the production of infant formula (powder milk) from sheep's milk and whey. The factory will be located in the industrial site of Tossilo (NU), Sardinia, which hosted in the past some manufacturing companies and is currently being converted to a logistics site due to its central position. The new plant is currently in its executive design phase and one of the main targets is the achievement of highly sustainable performance.

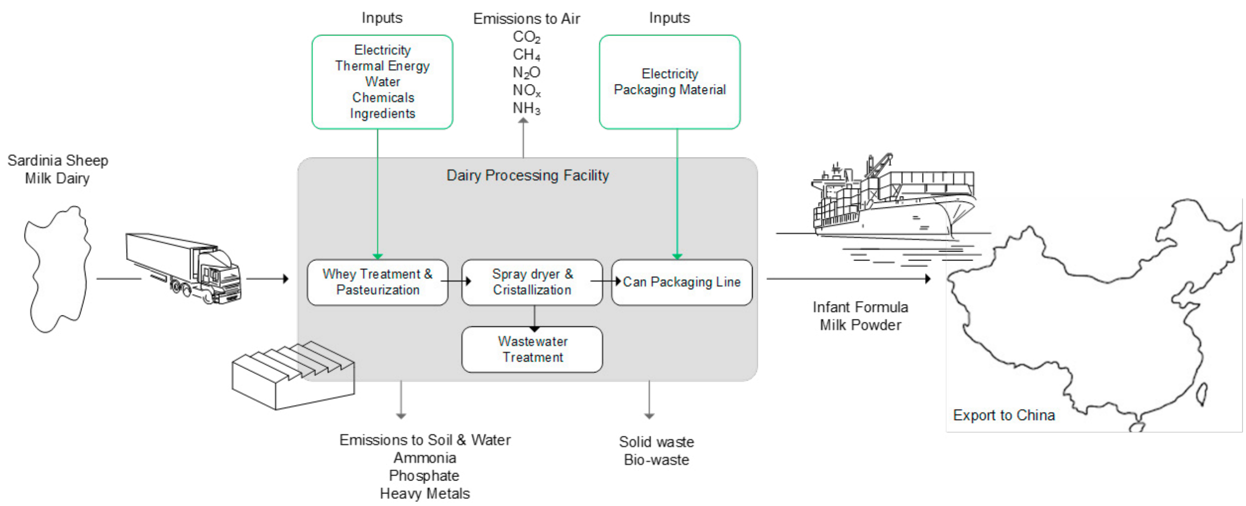

Fig.2: Scheme of the milk powder production process.

Figure 2 shows the simplified scheme of the milk powder production process with the main input and outputs. The

LCA study has been carried out through the SimaPro 9.1.1.7 software and the Ecoinvent 3 database. The LCIA is based on the new Sustainable method 2021 and the functional unit is represented by 1 kg of powder milk. Table 2 shows the main assumptions for the LCA study. In particular, because energy supply is the most relevant factor on the environmental performance of this production process, different energy supply options have been considered. The reference scenario is based on the supply of electrical energy from the grid and the use of fossil fuels (liquefied natural gas, LNG) to produce the required thermal energy. Firstly, the LCA results of the new plant were compared with European Irish and Spanish plants that alternately produce milk powder from cow's milk (Finnegan et al., 2017), cheese from cow's milk (Garcia and Berlin) and production of powdered milk from the tailors of cheese making (Garcia). This comparative analysis allows to validate the environmental indicators.

The factory is owned by both Italian and Chinese investors. In fact, the Chinese market requires a niche children product based on sheep proteins due to the lower intolerances compared to bovine proteins. The choice of the Sardinia site arose from the high production of sheep milk and the presence of many dairies. The dairies and sheep farms are located within 50-100 km from the new factory. Many different supply scenarios based on a different mix of input materials (sheep milk, whey or their mix) and energy (power and heat) can be considered. In particular, the complete or partial substitution of milk with whey leads to significant benefits for the FSC since whey is the main waste in dairy processing. The collection and the use of the whey by the new factory is a significant economic and environmental benefit for dairies because allows to solve its disposal problem. With reference to energy supply, it should be mentioned that Sardinia is the only Italian region without a natural gas distribution grid. For this reason. most industrial processes use oil products for heat production and electricity from the national grid. However, the first LNG (Liquefied Natural Gas) depot just started operation in 2021 and electricity production from renewable sources is becoming increasingly competitive. Therefore, five energy input scenarios based on photovoltaic plants (PV), wind turbines (WT) and Combined Heat and Power (CHP) systems have been considered (Table 2). Moreover, the processes data of Table 2 refer to the real project of the new plant, as authorized by the Sardinia Region and from the requests for the finished product. Other data are taken from the cited literature.

Table 2: Main assumptions for the LCA studies

Scenarios	Input 1 kg product	Energy input:
ALIMENTA WHEY	Raw material is 100% Whey waste from sheep's milk processing in Sardinian dairy	e.e.0.48 kWh (Market) , e.t 3.2 kWh (GNL)
ALIMENTA SHEEP MILK	Raw material is 100% Sardinian sheep's milk	e.e.0.48 kWh (Market) , e.t 6.68 kWh (GNL)
INFANT FORMULA COMPLETE	Raw material is 56% Whey waste from sheep's milk processing in Sardinian dairy	e.e.0.75 kWh (Market) , e.t 4.48 kWh (GNL)
I.F.C + PV 50 %	“	e.e.0.375 kWh (Market),0.375 kWh PV e.t 4.48 kWh (GNL)
I.F.C + WT 50 %	“	e.e.0.75 kWh (Market) , 0.375 kWh WT e.t 4.48 kWh (GNL)
I.F.C + CHP 100 % EE	“	e.e.0.75 kWh CHP (GNL) e.t 0.87 kWh CHP (GNL) 3.61 kWh (GNL)
I.F.C + CHP 100 % ET	“	e.e.3.86 kWh CHP (GNL) + 3.11 SURPLUS TO MARKET e.t 4.48 kWh (GNL)
I.F.C + CHP 50 % ET	“	e.e.1.93 kWh CHP (GNL) + 1.18 SURPLUS TO MARKET e.t 2.24 kWh CHP (GNL), 2.24 kWh (GNL)

3.1. Logistic and geographical dimensions

Alimenta's supply chain is perfectly integrated from upstream to downstream. The company collects sheep's milk and / or whey (waste product) from suppliers located in the area through a fleet of refrigerated vehicles. The raw materials entering the factory are transformed into milk powder. The finished product is sent to the sorting centers, from which it is then sent to the customers.

4. Results and discussion

Figure 3 shows the results of the LCA analysis applied to the milk powder production process by considering three different feedstock options: sheep milk, sheep whey and their mix used by Alimenta. By applying the Sustainable Impact 2021 method, Figure 3 shows that the use of sheep milk leads to the greatest environmental impact, mainly due to the high values of the Global Warming and Terrestrial ecotoxicity indicators (kg TEG soil). In fact, in this case, the GWP is 5.52 kg CO_2 eq against 0.9 kg CO_2 eq of the whey option and 2.15 kg CO_2 eq of the milk and whey mix option. Higher values are also found in the social indicators life expectancy (PersonYr) and Severe morbidity (PersonYr).

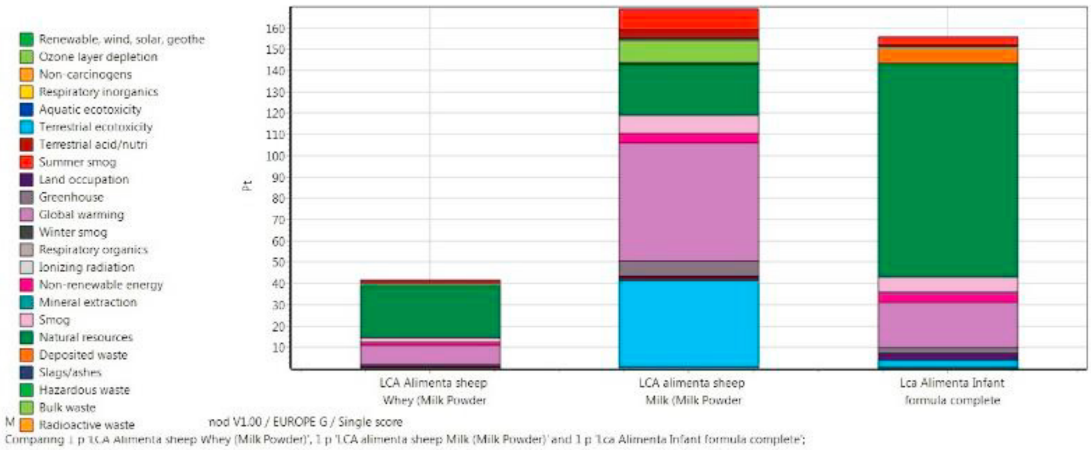

Fig.3: LCA results for the three feedstock options.

Figure 4 shows the LCA results achieved by grouping the various indicators into the environmental, social and economic damage categories. As expected, the Sheep Milk Scenario is the worst one. The only exception is the Infant Scenario formulating environmental indicators as the impacts of sheep's milk are present but also a greater consumption of renewable energy. (Fig 4)

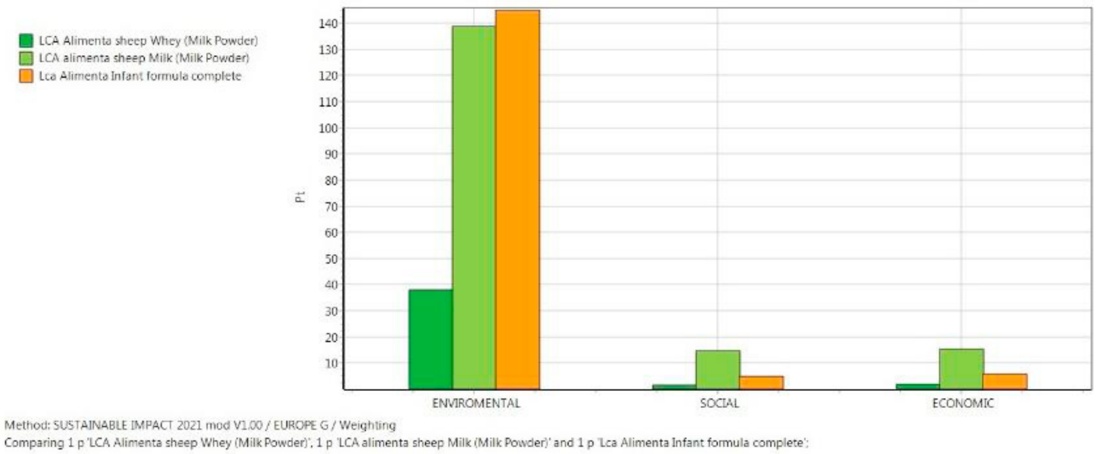

Fig.4: Damage categories for the feedstock scenarios.

Figure 5 shows the results of the LCA analysis by considering the different energy supply options. In comparison to the reference option, all the scenarios that replace fossil fuels with renewable energies lead to improvements of the environmental profile of the process. Similarly, scenarios based on the use of combined heat and power units report positive results in the LCA analysis. In some cases, a surplus of energy is produced which can be accumulated or sold to the electricity grid. The use of RES and CHP solutions also lead to improvements in the Smog, Deposited waste and Habitat alteration indicators. The best scenario is given using a CHP unit designed to produce the entire electricity demand, with a GWP of 1.77 kgCO_2 eq. The functional unit is 1 kg Milk Powder.

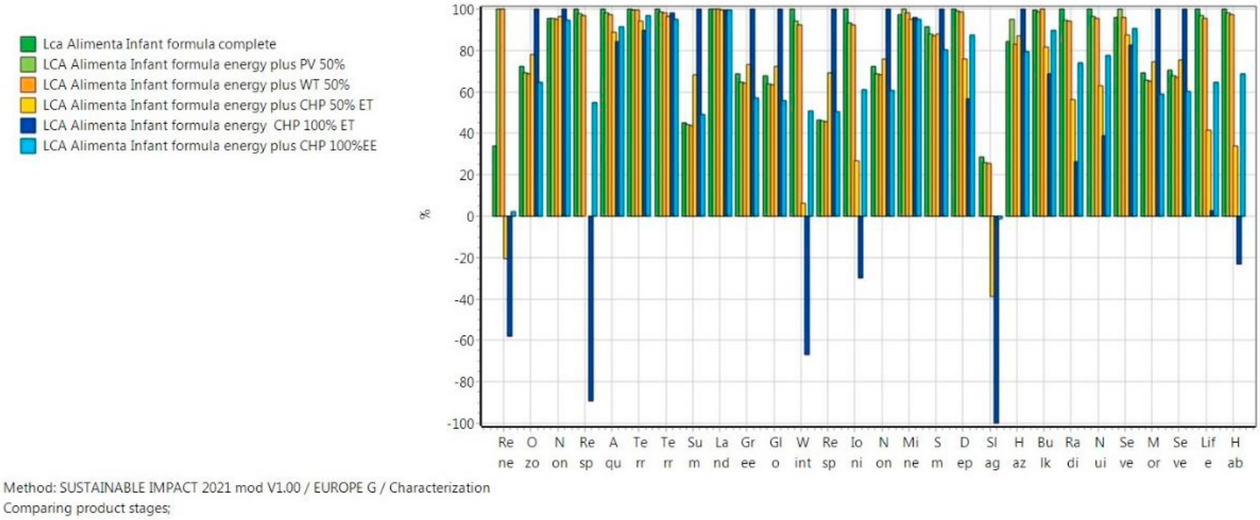

Fig.5: LCA results for the different energy supply options.

Figure 6 shows the LCA results achieved by grouping the various indicators into the environmental, social and economic damage categories. Figure 6 confirms that the best scenario is based on the use of a CHP unit designed to produce 100% of the electricity demand of the milk powder production process.

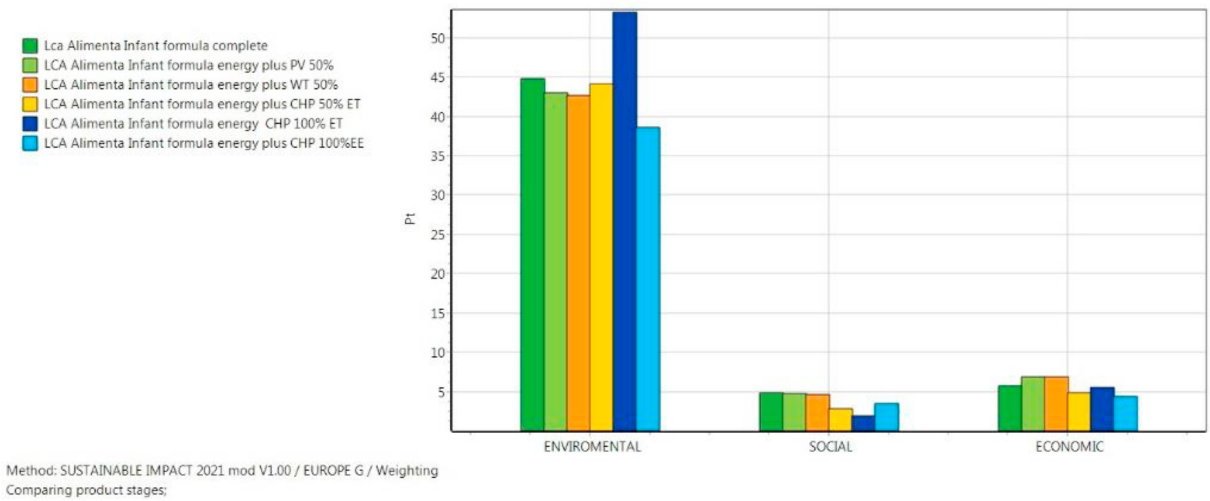

Fig 6: Damage categories for the energy supply scenarios.

Table 3 gives the results achieved by associating the indicators of the LCA analysis to each SDG, as validated by the Network algorithm (fig 1).

Table 3. Compliance with the SDGs of Agenda 2030.

Scenario	SDG#7	SDG#8	SDG#9	SDG#12	SDG#17
Alimenta Milk	87.84	67.03	65.43	66.03	14.18
Alimenta Whey	14.90	12.29	3.56	3.61	3.18
Infant formula complete	46.96	39.37	14.68	14.85	10.70
PV 50%	46.27	37.74	15.59	15.75	11.62
WT 50%	45.6	37.48	15.54	15.70	11.58
CHP 100% EE	39.54	33.60	12.75	12.89	8.9
CHP 50% ET	45.60	38.64	13.63	13.78	10.05
CHP 100% ET	55.53	46.89	15.06	15.23	11.70

In examining the compliance of the different scenarios with the SDGs, Table 3 shows the strict correspondence to goal 7 and that for all goals the most sustainable scenario in terms of feedstock is always the one in which the production of powdered milk is only based on the use of whey. With reference to the energy supply options, the best response to the Goals is given by the scenario where 100% of electricity and heat are produced with a CHP unit.

Conclusion

As mentioned, this paper aims to propose a new tool to support the decision-making process by including the sustainability factors considered by the SDGs. In particular, the proposed methodology investigates the connections between the environmental, social and economic impact categories considered by LCA studies and a selected set of SDGs included in the UN 2030 Agenda. Connections between SDGs and impact categories are firstly analyzed through a network algorithm, which measures the node's ability to communicate directly with other nodes. The LCA approach is used to weigh the impact categories and give a metric for the SDGs.

The application of the method to the new milk powder factory to be established in Sardinia demonstrates the ability to give a metric to measure the compliance with the SDGs. In particular, for the case study here discussed, the method shows that the use of whey as feedstock and the production of electricity and heat by means of a CHP unit allows to better comply with the SDGs of the Agenda 2030.

The conclusions with respect to The environmental indicators clearly show the benefits given by a supply chain and a production process using by-products and efficient energy conversion processes. This information can be useful in new activities design. To improve the method, future developments will focus on the inclusion of social indicators, in particular with reference to working conditions and population acceptability.

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