An integrative approach improves sustainability impacts of innovation. An empirical study

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***Abstract*—A review of recent literature in the field indicates there is an increasing interest in improving sustainability performances of manufacturing. The integrated innovation of product, process and supply chain can be a promising way to improve economic, social and environmental performances of manufacturing enterprises, but there is still a lack of empirical evidence on the topic. This paper compares the sustainability-related performances of three different states, which a unique business context went through. The final state, a small-sized mini-factory for the local transformation of sheep wool, outperforms the other (more traditional) configurations in terms of social end economic impacts, with just partial advantages in terms of environmental performances.**

Keywords—sustainability; wool manufacturing; integrative innovation approach; mini-factory; local vs. global production and supply chain

I. INTRODUCTION

Innovation in manufacturing contexts may derive from and result into changes ranging between small, incremental adjustments to multi-layer multi-disciplinary disruptions. Traditionally, the great part of innovation initiatives addressing manufacturing contexts are triggered by economic and financial goals, even if, in recent years, some methodologies and approaches emerged aimed at integrating all the three sustainability dimensions (triple bottom line: [1]) into innovation-related decision making. This is a result of an increasing pressure from the market on including (also) environmental and social elements in business model evolution. In general, as each sustainability issue gains relevance in the strategy of a company, more extensive changes of the company have to be performed ([2]) but, vice versa, does a wider, multi-layer, integrative approach to innovation increase the opportunity for a sustainable development?

This paper is meant to empirically demonstrate that sustainability-focused strategies innovating more business model blocks at the same time, are more effective in pursuing sustainability than single-block strategies. The proposed empirical point of view is reasonable as far as: (i) different scenarios can be derived from a unique business context that (radically) innovated over a medium-term time horizon modifying product, process and supply-chain; (ii) all the three dimensions of sustainability are relevantly represented; (iii) standardized and measurable metrics can be applied to reliable input data for an effective comparison of the selected scenarios.

The WoolTI project, involving researchers, manufacturing companies and an association for the preservation and promotion of handicraft in the Swiss Tessin area, had the goal to promote a local handling, processing and valorization of sheep wool. In Tessin region, a gradual abandonment of mountain land activities occurred in the last decade[1], also bringing to a decline of the local artisanship. WoolTI aimed at developing new technologies and supply chain agreements in order to promote the local valorization of small quantities of wool, through a traceable "from sheep to shop" path. The initiative was initially triggered by social elements, such as the preservation of local traditions and cultural heritage; the identification of new aggregation opportunities for the rural community; local breeders looking for complementary incomes to keep staying in such an (economically) unfriendly environment; the opportunity to improve local employment. The WoolTI innovation initiative complies with point (i) of the above-mentioned requirements for an empirical approach. In fact, it started in 2008, when locally-produced wool was treated as a pure waste. Here we took the first reference picture, also used as a baseline scenario. Starting from 2009 and until 2013, the local association collected and processed the locally produced wool. The most critical processes (namely: wool washing and drying) were performed by third party large-scale plants located outside the region. Here we took the second reference picture useful for performance comparison. Finally, thanks to an integrative research and innovation initiative, the WoolTI project reached the third phase (2014), in which new wool washing and drying technologies have been developed (down-scaling mass-production machines) and installed in a Tessin plant in order to have a fully local production of wool.

According to (ii), this multi-disciplinary project impacts on the social, environmental and economic dimensions thanks to the preservation of rural and craft activities (from breeding to wool-based artifacts production) and the start of a local semi-industrial and profitable production. In the end, reliable data describing all the three pictures are available and appropriate sustainability-related metrics have been selected to comply with point (iii) above.

[1] http://www4.ti.ch/dfe/dr/ustat/ufficio/

This paper is structured as follows. In the second chapter the research background is briefly addressed. Then, the adopted research methodology (§III) and the case study (§IV) are detailed. In chapter V, the performed sustainability assessment is described in detail, highlighting which are the input data for each case and for each indicator, in order to enable an accurate pondering of the obtained results (§VI). The last chapter deals with the conclusions and summarizes the core findings of this paper.

II. Relation to existing theories and work

As stated in [1], most models and tools proposed for sustainability assessment just focus on the environmental dimension of sustainability and the great part do not have an operational attitude (namely: just few tools are available for pondering the sustainability impacts and they only focus just on one sustainability dimension). Sustainability is indeed rarely and only partially measured in industrial contexts, even if an increasing number of manufacturing enterprises ask for effective and reliable assessment and advisory instruments supporting decision making for sustainability. Traditional manufacturing contexts are even more un-literate concerning the sustainability concept and its application. Specifically, in the wool sector, just a few studies are available, merely focussing on environmental impacts assessed in large-scale mass-production [4]. Several Life Cycle Assessments (LCAs) have been completed for evaluating wool production, focussing on heterogeneous goals, scopes, data sources, and critical assumptions (e.g.: [5],[6],[7],[8]); these studies demonstrate the positive (environmental) contribution of the livestock breeding phase in the lifecycle analysis of many wool products in apparel and interior design industries, and they provide best practices and guidelines to improve the wool-based business to an even higher standard. But still, in all cases, neither economic nor social ponderings have been performed.

Interestingly, there is a dearth of literature investigating the correlation between the sustainability impacts of a manufacturing context and the kind of adopted innovation process. Few cases partially address this topic, investigating the correlation between the implementation of an integrative (product-process-supply chain) approach to innovation and the environmental performances of the resulting manufacturing environment (e.g.: [9],[10]). These studies are mainly intended to prove the effective application of three-dimensional concurrent engineering concepts for achieving an environmentally responsible manufacturing. Nevertheless, they all focus on the design process and specifically on concurrent engineering, and they do not provide empirical evidence of the existing correlation between the environmental impacts and the adopted integrative approach to new product development.

WoolTI is an interesting and effective case study for performing a sustainability assessment since it is a representative case of the development of a mini-factory [11] in the wool sector. In particular this case study has been selected because:

- the mini-factory concept is an evolving and pervasive trend amongst production models, with clear promising applications in specific manufacturing contexts;
- the centralization and the small dimension of the production plant allow to easily perform the data gathering activities for the sustainability assessment and to have a shorter "time to integrative reconfiguration" (thus easing and speeding up the implementation of multi-layer innovations);
- the concept of mini-factories close to suppliers and customers has been developed as a valuable mean to pursue economic, and especially social and environmental requirements. This makes such an object a perfect target for a complete sustainability assessment.

The proposed investigation aims at creating additional knowledge on the sustainability impacts of a mini-factory created through a multi-layer, integrative innovation approach.

III. Research approach

As mentioned in §I, the main objective of the presented study is to analyse the sustainability impacts of three different wool handling/treating processes, having in common the raw material and varying in terms of product characteristics, processing technologies and supply chain configurations. The pondered processes are real pictures captured in three instants of the evolutionary lifecycle of a Swiss-centred wool processing. These three pictures are all described in detail in §IV, and analysed on the basis of their impacts on sustainability. In order to perform a quantitative measurement of environmental, economic and social performances, nine indicators have been selected and calculated for each case and used for comparison.

Adopted indicators have been selected amongst literature-documented sets ([12]) and then partially adapted in order to better seize the taste of the specific case study (in

table I a list of the adopted indicators is reported). According to the triple-bottom-line approach ([1]), three sets (of three indicators each) have been used to measure the sustainability impacts/performances. The first group of three indicators is meant to ponder the environmental impacts. Starting from a set of 12 environmental indicators mentioned in [12], the selected three were the best performing considering: (i) recognisability (also for non-literate readers); (ii) significance for the analysed business case and (iii) availability of data. All these indicators have been calculated by performing a LCA analysis, consistently with ISO 14040:2006 [13]. Process and product data required as inputs to LCA have been directly gathered on the field and processed using the GaBi Software Database[2] and the ecoinvent v2.2 database[3]. The three economic impacts indicators have been selected covering all the three aspects mentioned in [12]: one for efficiency, one for profitability and one for investments. Finally, social impacts indicators have been selected starting from the list presented in [3] and [12] and leaving aside not relevant and not easily computable ones (e.g.: injury intensity, workforce turnover, child labour). Given the peculiarity of the examined case study, one social indicator has been properly

[2] http://www.gabi-software.com/international/databases/

[3] www.ecoinvent.org/database/

defined considering a set of dimensions describing (rural/mountain) land abandonment, as illustrated in [14].

The rationale of each indicator choice and the adopted procedure for each indicator calculation are detailed in §V.

TABLE I. LIST OF SELECTED SUSTAINABILITY INDICATORS FOR THE PERFORMED STUDY

	Indicator	Description	Unit
ENVIRONMENTAL	GWP	The Global Warming Potential indicator measures the contribution to global warming caused by the emission of Green House Gasses to the atmosphere over a 100-year time horizon.	Kg CO_2 Eq.
	HTP	The Human Toxicity Potential indicator measures the relative impact of toxic substances on human beings related to the emissions in environmental compartments, namely: air, freshwater, seawater, agricultural and industrial soil.	Kg 1.4-DB Eq.
	WD	The Water Depletion indicator measures the water consumed during the whole lifecycle of the product (within the identified boundaries of the analysis as described in §V.A).	m^3
ECONOMIC	TUAC	The Total Unitary Absorption Cost indicator measures the total industrial cost of a transformation process; it includes the material and personnel costs, and indirect production costs allocated to the analysed operations.	CHF[4]
	UEGP	The Unitary Expected Gross Profit indicator measures the difference between the unitary revenue (namely: the unitary selling price) and the unitary full cost.	CHF
	RDII	The R&D Investment Intensity indicator measures the research and development investments performed by actors within the boundaries (described in §V.A) allocated on the solution space.	CHF
SOCIAL	LS	The Local Supply indicator measures the percentage of the costs related to operations performed *locally* with respect to the costs of the operations performed along the analysed supply chain.	%
	EO	The Employment Opportunity indicator measures the working hours required for all the product transformations within the analysed supply chain.	h
	RLP	The Rural Land Preservation indicator provides a qualitative measurement of the contribution that a given wool transformation process provides to the local community in terms of preservation of rural inhabitants, culture, heritage safeguarding.	%

IV. CASE STUDY

The case studies presented below are three different pictures taken in three different lifecycle phases of the WoolTI initiative. WoolTI, a business/research initiative managed by a Swiss-based (Tessin canton) foundation, started in 2008 with the goal of exploiting the wool produced by small communities of farmers/breeders located in the Tessin mountain region, moving from an expensive and impacting waste to be disposed, towards a valuable and profit-generating resource. Triggered by social motivations (such as opposing the gradual abandonment of peripheral locations), WoolTI has gradually become a more complex and multi-faceted initiative, with direct impacts also on economic and environmental dimensions. The three pictures, which we took of this evolution, form the three cases compared in the paper. Refer to Fig. 1 for mentioned actors' geographical collocation.

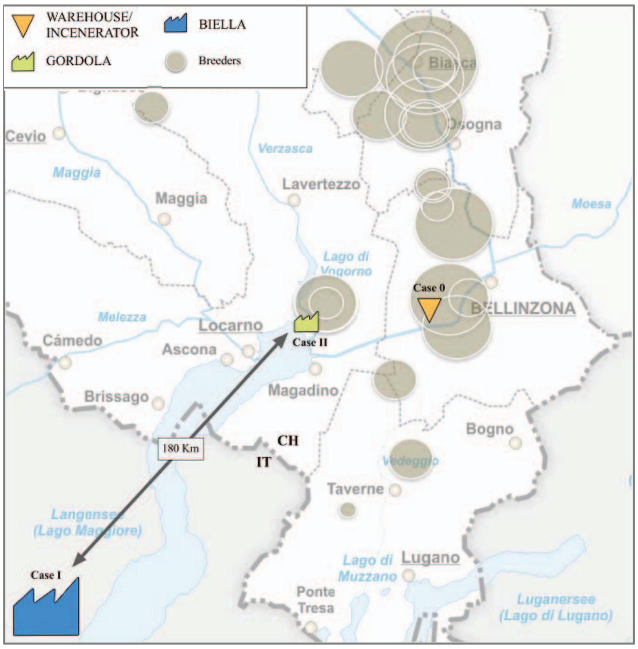

Fig. 1 Locations of the three cases' supply-chain actors

Case 0 – Baseline

Case 0 is used as a baseline in the following comparisons. It refers to the wool management approach before 2008 (namely: before the WoolTI initiative): wool is completely handled **as waste**. In fact, after the shearing phase, wool was collected from farms to a central **warehouse**, located in Tessin and burned in an **incinerator**.

Case I – Product and supply chain innovation

In Case I (years 2009-2013) the greasy wool is no more considered a waste: it is collected from each farmer and stocked in a central **warehouse** in Tessin (few km far from the incinerator mentioned in Case 0). The whole collected wool is then transported to a **third-party service provider** located near Biella, in Italy (180 km far from the warehouse), where it is washed and dried in order to obtain clean wool flakes[5]. This output is then brought back to a small plant next to the Tessin warehouse where amateur craftsmen produce hand-made wool-based garments, artefacts, etc.

Case II – Process and supply chain innovation

Thanks to a research project carried out together with the local university, **WoolTI went completely local** as of 2014. The greasy wool is collected by each farmer and stocked in the production plant located in Gordola, Tessin (see Case I). Thanks to the introduction of new technologies such as a downscaled washing machine and new drying machine, the

[4] We used the local currency: Swiss franc.

[5] The external industry requires 10'000 kg of greasy wool as minimum lot to start its production otherwise it is not profitable; the annual wool production in the Tessin region has been estimated equal to 3'700 kg in 2014.

small collected batches of wool are directly processed in the local plant. The developed process is completely new and is compliant with the same operating principle of the large-scale production. Similarly to Case I, once the wool is cleaned, it is processed to get hand-made artifacts to be sold in a local store near the production plant.

V. SUSTAINABILITY IMPACT ASSESSMENT: METHODS AND INDICATORS

As mentioned, all the three dimensions of sustainability have been assessed. While for environmental sustainability various standards are available supporting a proper implementation of data gathering and data processing, social and economic sustainability assessment is often performed in accordance to *ad hoc* defined procedures. In this study, we decided to rely on ISO 14040:2006 standard to perform a reliable LCA analysis of environmental impacts, and to use the same data gathering procedures, simplifying hypotheses, and boundaries also for the social and economic dimension. In §V.A the common hypotheses are discussed, while in §V.B, the three indicators selected for each dimension are presented and discussed, together with the detailed gathering methodology and data handling procedure.

A. Goal and scope definition

The goal of the presented study is to analyse specific production sites and supply chains using data collected from three real cases (actually: the same *initiative* in three different years), in order to quantify their impact hotspots and verify the improvement of sustainability impacts at different levels of innovation. The elements that need to be preliminarily defined for carrying out this analysis are the **functional unit** and the **system boundaries**.

The functional unit enables the comparison between the different scenarios and, in fact, its definition has to be done considering the processes to be compared. In order to compare the wool-exploiting case studies (I and II), the chosen functional unit is one kilogram of cleaned and dried wool flakes. However, this unit cannot be used to analyse Case 0. Considering washing and drying process efficiency for Cases I and II (that are identical), 1 kg of cleaned and dried wool derives from 1.59 kg of greasy wool that enter the production process (equation (1)). Even though in the Case 0 the more logical functional unit couldn't be applied in that form, the corresponding unit of greasy wool can be used as well. Thus, the **functional unit becomes 1.59 kg of greasy wool**.

$$Greasy\ wool = \frac{Wool\ flakes}{Efficiency} = \frac{1\ kg}{0.63} = 1.59\ Kg \qquad (1)$$

The system boundaries settle which elements of the process shall be included in the LCA. The area where the LCA analysis has been performed includes all the processes going from the transportation of the greasy wool down to wool scouring (washing) and drying. Animal breeding and related activities have been left aside, both because not intrinsically allocable to the wool product, and because not differential among the three scenarios. Operations performed after the drying process have been left aside because not differential between Case I and Case II. It must be noted that for Case 0 the LCA ends with the incineration of the greasy wool. Analysed process steps for the three cases are represented in Fig. 2.

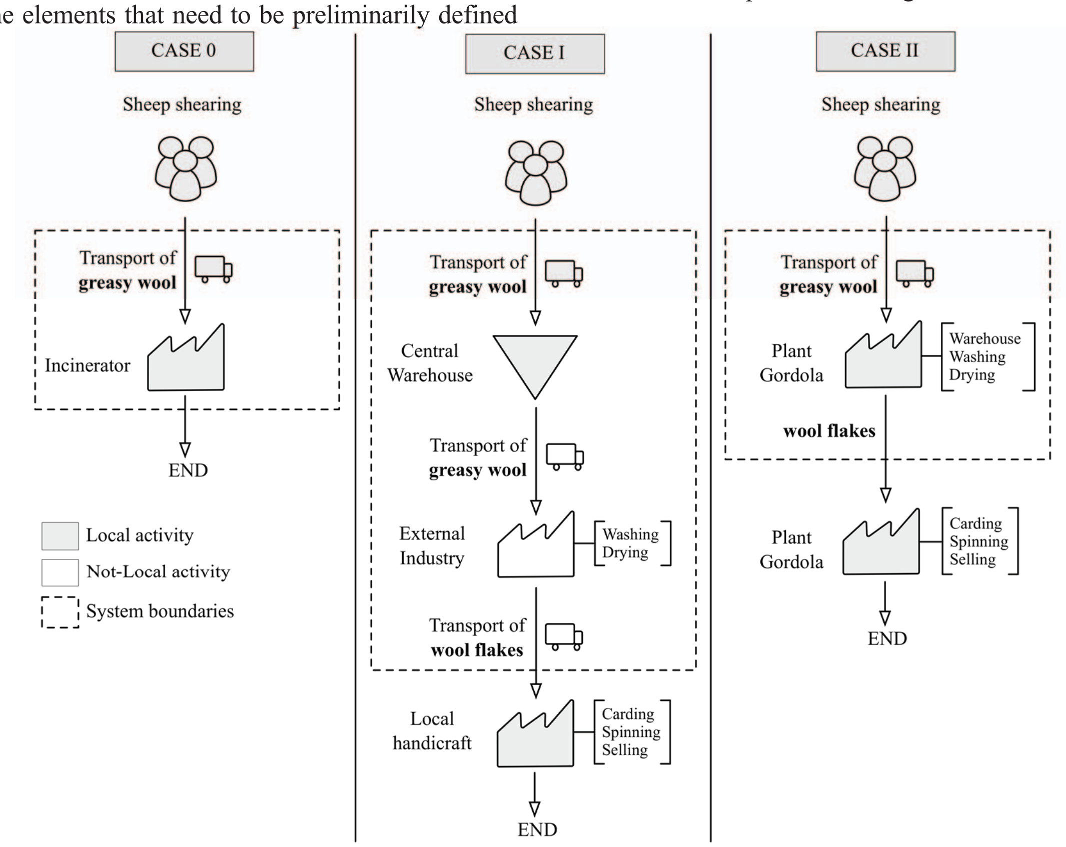

Fig. 2 Representation of the system boundaries for LCA

B. Environmental dimension

1) Life Cycle Inventory analysis

The Life Cycle Inventory (LCI) analysis is a methodology for estimating the consumption of resources (inputs) and the quantities of waste flows and emissions (outputs) generated by a production system. The processes within the life cycle, the associated material and energy flows are modelled to represent the product system and its inputs and outputs from and to the natural environment. Data concerning impacts of electricity, fuel, water, wool, etc. have been extracted from the GaBi Database and ecoinvent database, and are all referred to the defined functional unit.

For Case 0, the inventory data collection is immediate, because there is only one process from which inputs, outputs, energy flows and waste are extrapolated. The input flows consist of greasy wool and its transportation distance from the farm to the incinerator. GaBi Database offers a pre-defined block process dedicated to incineration. Table II includes all the required inputs for this operation. The wool collection and transportation flows have been included as independent blocks.

For Case I, additional processes have to be considered and further data to be collected. The starting point is the same as Case 0, inasmuch the greasy wool is transported from the breeders to a central warehouse (next to Case 0's incinerator). As described in §IV, the washing and drying operations are performed in outsourcing by an external industry. Transportation of the (way toward: greasy, way back: washed and dried) wool and the distance between the warehouse and the external industry have been included in the analysis. With GaBi Software, two dedicated blocks have been created simulating these two processes. The other blocks represented in Fig. 3 are predefined and directly included inside the simulation, using quantities listed in Table II.

As represented in Fig. 4, Case II is similar to Case I in terms of use of resources (except for the use of the caustic soda during the washing process) and in terms of typology of considered equipment (processes are the same, but performed with different machines).

In Table II the detailed list of data considered in the LCA analysis is reported, each of them has been calculated referring to the defined functional unit.

2) Life Cycle Impact Assessment

According to ISO 14040, the Life Cycle Impact Assessment (LCIA) is aimed at evaluating the significance of potential environmental impacts using the results of the LCI analysis. The impact assessment phase was performed using the ReCiPe life cycle impact assessment method [15].

Concerning the environmental dimension, it is important to consider relevant indicators for the analysed cases. In this study, three indicators have been selected in order to evaluate the environmental sustainability: Global Warming Potential, Human Toxicity Potential and Water Depletion (see

table I for their definition).

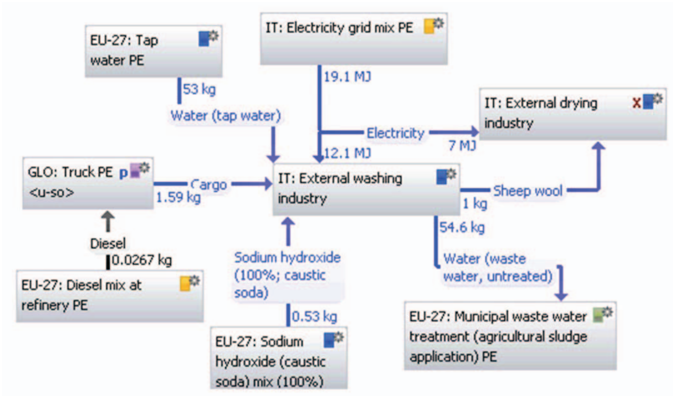

Fig. 3 GaBi processes representation for Case I

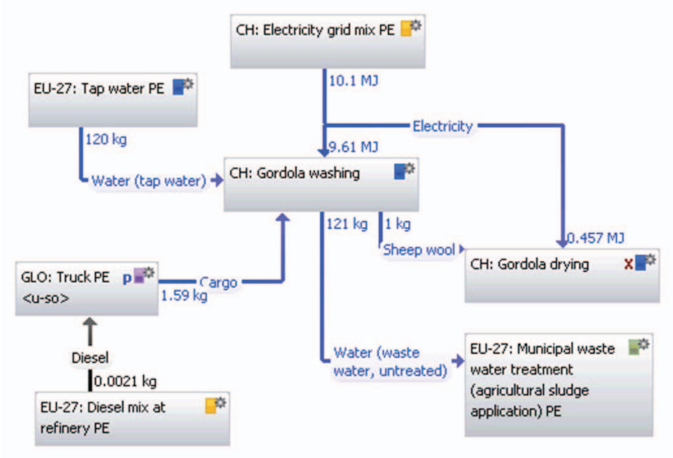

Fig. 4 GaBi processes representation for Case II

TABLE II. LIST OF DATA CONSIDERED IN THE LCA ANALYSIS

Item	Data source	Case 0	Case I	Case II
Incinerator	EU-27: Waste incineration of textile fraction in municipal solid waste	-	-	-
Electricity	CH: Electricity grid mix PE	-	-	10.1 MJ
Electricity	IT: Electricity grid mix PE	-	19.1 MJ	-
Water inlet	EU-27: Tap water PE	-	53 Kg	120 Kg
Wastewater treatment	EU-27: Municipal wastewater treatment	-	54.6 Kg	121 Kg
Truck	GLO: Truck PE – van up to 3,5t	29.9 Km	400 Km	31.5 Km
Fuel	EU-27: Diesel mix at refinery PE	0.002 Kg	0,0267 Kg	0.0021 Kg
Soap*	Soap, at plant	-	0.48 Kg	0.0127 Kg
Caustic soda	EU-27: Sodium hydroxide mix PE	-	0.53 Kg	-

* The soap data have been extracted from the ecoinvent v2.2 database.

The first and second indicators have been selected as the most representative in a LCA analysis: GWP provides global information of the CO2 emissions in the atmosphere; HTP provides the relative impact of toxic substances on human beings. The last environmental indicator (WD) has been selected in order to compare the consumption of water within each case.

C. Economic dimension

In order to analyse the economic impacts of the cases study, three indicators have been selected.

The first used indicator is the **Total Unitary Absorption Cost** (TUAC), in order to evaluate the costs of each analysed production site. In Table III the cost items considered in the TUAC calculation are listed, all referred to the defined functional unit. As shown in the table, in Case 0 the raw material has null cost because it is property of the breeders. For Case I, the breeder is rewarded 1 CHF per kg of greasy wool, while in Case II the reward is doubled as a compensation for the breeders actively participating through a pre-selection and pre-packaging of the greasy wool. The manufacturing costs for Case 0 are null; in Case I they are equal to the amount paid for the outsourced process; finally, for Case II the manufacturing costs have been calculated considering direct costs and indirect costs, the latter allocated using the following principles:

- machinery: depreciation of the machines;
- loan building and maintenance: space occupied by the machines;
- personnel: time worked on washing and drying;
- energy: consumption energy of the machines.

TABLE III. TUAC CALCULATION: LIST OF COSTS CONTRIBUTIONS FOR PROCESSING 1.59 KG OF GREASY WOOL IN CHF[6]

Cost item	Case 0	Case I	Case II
Raw material	0.00 CHF	1.59 CHF	3.18 CHF
Transportation	0.42 CHF	0.66 CHF	0.49 CHF
Manufacturing		6.36 CHF	
- Machinery			1.14 CHF
- Loan building			1.55 CHF
- Personnel			4.51 CHF
- Energy			0.98 CHF
- Maintenance			0.32 CHF
TUAC	0.42 CHF	8.61 CHF	12.17 CHF

The **Unitary Expected Gross Profit** (UEGP) has been selected in order to evaluate the profit generated in each case study. The calculation is consistent with the TUAC one, but other costs (administration, promotion, insurance, etc.) are also included and allocated using the time worked in the washing and drying operations (see Table IV). Moreover, it must be noted that manufactured products in Case II are better perceived by the customer, who recognises a premium price.

TABLE IV. UEGP CALCULATION: LIST OF CONTRIBUTION OF COST AND PROFIT WITH REFERENCE TO THE FUNCTIONAL UNIT

Item	Case 0	Case I	Case II
TUAC	0.42 CHF	8.61 CHF	12.17 CHF
Other costs	1.59 CHF	0.00 CHF	3.35 CHF
Total costs	2.01 CHF	8.61 CHF	15.52 CHF
Selling price	0.00 CHF	28.62 CHF	38.16 CHF
UEGP	- 2.01 CHF	20.01 CHF	22.64 CHF

The **Research and Development Investments Intensity** (RDII) has been selected to evaluate the incidence of the investments done in R&D within each case and has been calculated considering the ratio between the total investments and the quantity of wool produced in 5 years, as shown in Table V.

TABLE V. RDII CALCULATION, WITH REFERENCE TO THE FUNCTIONAL UNIT

Item	Case II
Investments	900'000.00 CHF
Annual wool production	3'700 kg
Wool production over 5 years	18'500 kg
RDII	77.35 CHF

D. Social dimension

In order to evaluate the social impacts of each case, three indicators have been selected, focused mainly on the benefits and consequences generated on the local community and environment.

The **Local Supply** (LS) indicator has been selected in order to measure the de-localization of processes; LS is the ratio between the local purchasing expenditures and the total purchasing expenditures considered within the analysed supply chain (see Table VI for calculation).

TABLE VI. LS CALCULATION: LIST OF THE LOCAL (IN ITALICS) AND NOT-LOCAL COST CONTRIBUTIONS OF PRODUCTION FOR EACH CASE, WITH REFERENCE TO THE FUNCTIONAL UNIT

Cost item	Case 0	Case I	Case II
Raw material	0.00 CHF	*1.59 CHF*	*3.18 CHF*
Transports to the warehouse	*0.42 CHF*	*0.42 CHF*	*0.49 CHF*
Transports to the external industry		0.24 CHF	
Manufacturing	0.00 CHF	6.36 CHF	*8.50 CHF*
Other costs*	*1.59 CHF*	0.00 CHF	*3.35 CHF*
Total cost	2.01 CHF	8.61 CHF	15.52 CHF
Local cost contribution	*2.01 CHF*	*2.01 CHF*	*15.52 CHF*
LS	100%	23%	100%

*Other costs refer to cost for administration, promotion, insurance, etc.

The second social indicator has been chosen to evaluate the **Employment Opportunity** (EO) generated in each case. The indicator has been calculated considering the hourly production and the working hours required to wash and dry 3'700 kg of greasy wool at the external industry and at the local plant (Table VII). 3'700 kg is the yearly overall amount of greasy wool produced and collected in Tessin.

TABLE VII. EO CALCULATION, WITH REFERENCE TO THE FUNCTIONAL UNIT

Item	Case I	Case II
Hourly production	650 kg/h	2.67 kg/h
Hours machine generated	5.69 h	1386 h
Hours required to transform 1.59 kg of greasy wool	0.0024 h	0.5955 h
% of operator working hours	100 %	30 %
EO	0.0024 h	0.1787 h

Finally, the **Rural Land Preservation** (RLP) is the last calculated social indicator. It results from the contribution of three main factors that allow to recognise when a production system directly provides benefits to the local community and preserves the cultural heritage. In Table VIII the selected factors and the coverage that each case has for these factors are listed.

[6] 1 CHF = 1.05 $ on 26.02.2015

TABLE VIII. RLP CALCULATION

Factor	Case 0	Case I	Case II
Local branding and traceability	0	1	2
Local training and tutoring efforts	0	0	2
Supplementary income for breeders	0	1	2
RLP	0%	33.3%	100%

Legend: 0 no coverage – 1 partial coverage – 2 complete coverage

The "local branding and traceability" aspect considers the possibility to certificate a product as PGI (Protected Geographical Indication) or PDO (Protected designation of origin)[7] for the production and also for the entire supply chain. The "local training and tutoring" is related to the possibility to transfer knowledge inside the community and to train the local breeders in order to enhance the quality of the sheared wool. The last sub-factor, i.e. supplementary income for breeders, considers the opportunity for the breeders to increment their own incomes selling the greasy wool and enhancing their breeding activity.

VI. RESULTS

In this chapter the results extracted by the calculation of the environmental, economic and social indicators are explained. A global overview of the results for all the calculated indicators is shown in Fig. 5; in Fig. 6 and in Table IX the detailed results are reported.

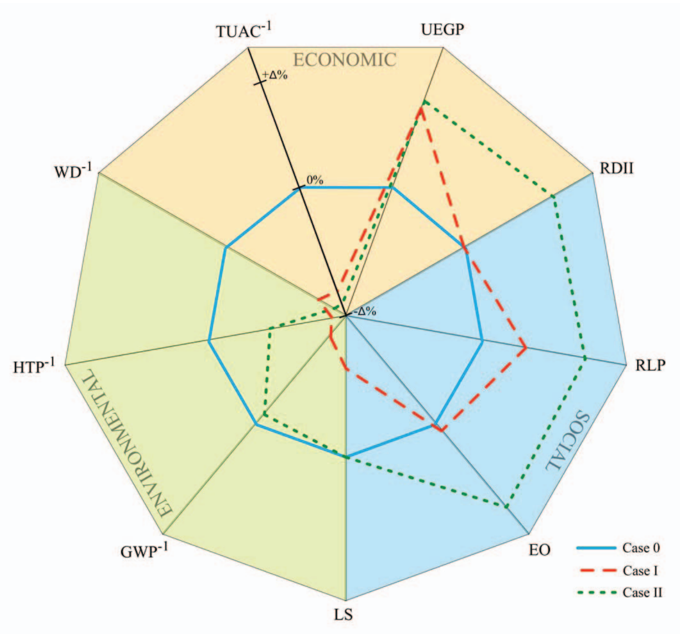

Fig. 5 Synoptic comparison of the resulted sustainable impacts of the three cases. Case 0 has been used as a reference case, while the impacts of the other two cases have been normalized and reported in the graph with reference to Case 0. Indicators whose increase indicates a worsening of the sustainability performance have been inverted (indicator $^{-1}$), thus, in the chart, positive incremental changes mean a better performance.

[7] http://ec.europa.eu/agriculture/quality/schemes/index_en.htm

TABLE IX. RESULTS OF THE ENV-ECO-SOC IMPACTS

	Indicators	Case 0	Case I	Case II
ENV	GWP [Kg CO_2 Eq.]	0.53	4.25	0.55
	WD [m^3]	0.01	19.42	25.00
	HTP [Kg 1.4-DB Eq.]	0.02	0.43	0.04
ECO	TUAC [CHF]	0.42	8.61	12.17
	UEGP [CHF]	-2.01	20.01	22.64
	RDII [CHF]	0.00	0.00	77.35
SOC	EO [h]	0	0.0024	0.1787
	LS	100 %	23 %	100 %
	RLS	0 %	33 %	100 %

A. Environmental impacts

For GWP and HTP, both Case 0 and Case II are good performers. This is interesting because it is not usual that a productive scenario has the same emissions as a disposal scenario. Almost all the emissions generated within Case 0 derive from the energy consumed by the incineration process. The worst situation for the GWP is Case I due to a high usage of electricity, soap, caustic soda and the long distances covered by the truck to transport the materials to the third-party service provider. Case I is the worst performer also considering HTP due to the high usage of soap. An interesting result is shown in the WD graph, where the worst situation is Case II: operations performed in Switzerland use locally produced energy, which has a high percentage of hydroelectric contribution.

B. Economic impacts

Regarding the economic dimension, Case 0 has the lowest performance being a non-productive situation without profits and investments. More considerations need to be done for the other two cases. As shown in Table IX, Case II has higher costs than Case I. This is justified by the fact that a large-scale production is more optimized than a local quasi-craft production. The greater profit of Case II production results from the premium price recognised by the customers for the certified "fully local" supply chain.

C. Social impacts

Within the social dimension more considerations have to be done. First of all, looking at Case II in Table IX, it is possible to understand how a localization strategy could bring benefits generating employment and preserving the rural land. For the LS indicator, Case II is the best solution together with Case 0, but with different weights (2.01 CHF spent in Tessin in Case 0, and 15.52 CHF for Case II). Concerning the EO indicator, results in Table IX show that Case II allows to generate more employment hours than Case I for the same reason mentioned before: local small-scale productions are less effective than large-scale mass-producing equipment.

The last social indicator is the RLP. Looking at Table IX, Case II is the best performer because all the identified sub-factors are completely covered. In fact, thanks to the adopted innovation, a local brand and PGI or PDO product certificates can be used to promote local culture and know-how. Moreover, Case II processing technology is quite sensitive to the quality of the input wool. This has forced the WoolTI team to organize training sessions for local breeders in order to give them an appropriate knowledge about the shearing and breeding

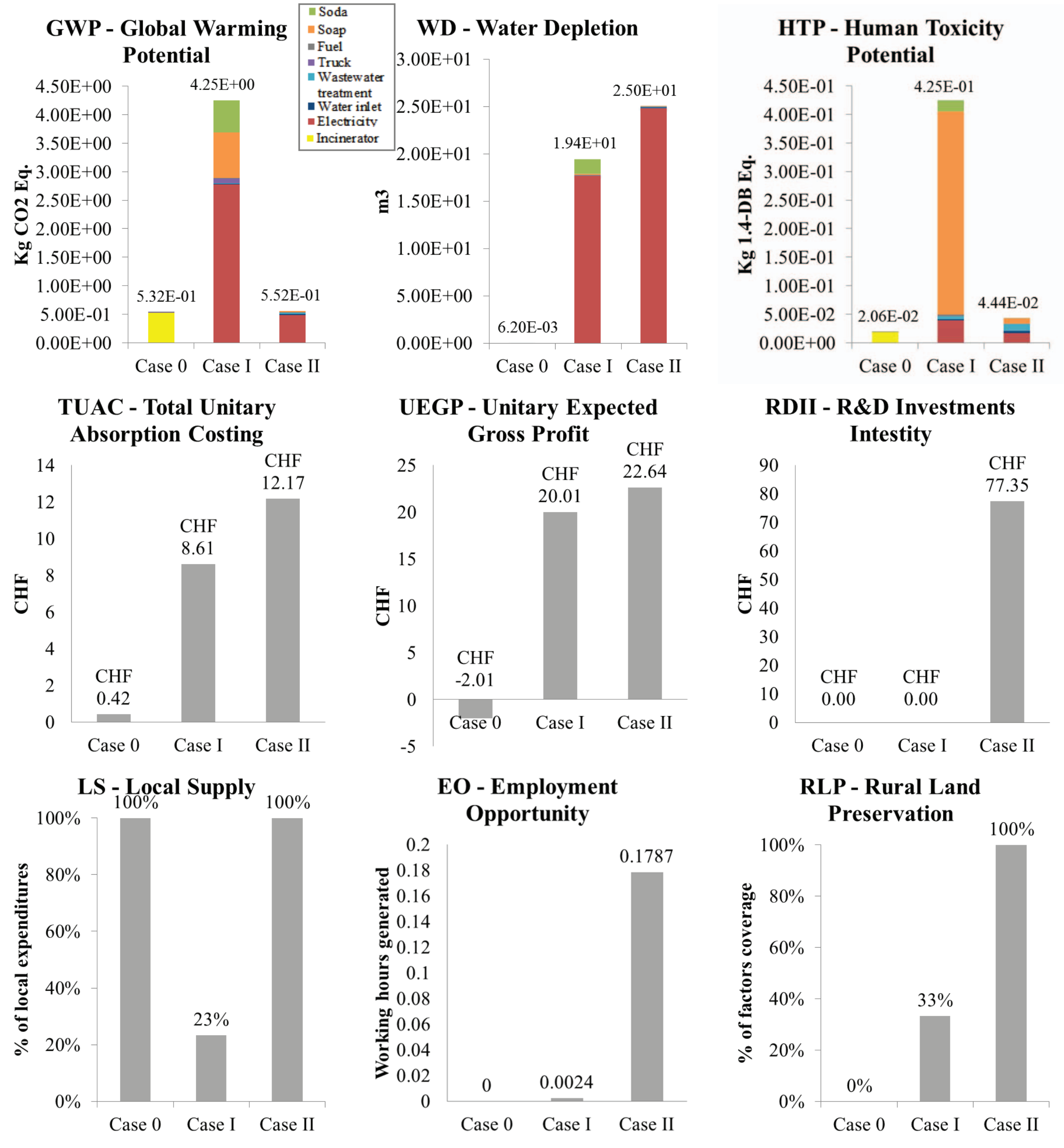

Fig. 6 Results of the indicators calculation

activities. This has resulted into a higher quality of the input, supplementary income for the breeders and many opportunities to reinforce local culture and sense of belongingness.

To summarize, Case II outperforms other scenarios in terms of social impact (actually, social issues were the trigger of the whole WoolTI initiative). Case I and Case II are both nicely performing from an economic point of view, with Case II costs and profits both higher than Case I's. Premium price recognised for the full-local traceable production is currently quite high and price elasticity of demand has still to be carefully pondered for high volumes of product. Finally, concerning the environment, under the presented hypotheses, Case 0 (not to produce) is the best performing choice.

VII. Conclusion

Using the WoolTI research/manufacturing experience, the paper compared the sustainability performances of three moments in an evolving business experience. Apparently, the integratively-developed mini-factory outperformed other scenarios in terms of social and economic impacts. Just partially from the environmental point of view. An empirical demonstration has been, thus, given of the initial hypothesis: adopting an all-encompassing approach, synergistically innovating the product, the process and the supply chain, results in a more sustainable alternative. Actually, some warnings must be noted: (i) nine indicators have been arguably selected. Other indicators could give other results. Nevertheless, the indicators selection process has been performed in a rational way, focusing on most significant and representative measures; (ii) the initial strategy of the WoolTI team was socially-driven, thus an already (even if partially) sustainability-driven innovation approach might not be the most representative sample for sustainability pondering. In mitigation: nowadays, the great part of innovation initiatives are socially-, environmentally- or even sustainability-driven, moreover the sustainability driver distinguishes two of the three analysed scenarios; (iii) finally, the paper relies on real-life gathered data, with a reasonable timespan for Case 0 and I, while just a limited amount of data available for Case II. This should result into a lower reliability of the registered results, thus further data gathering campaigns and validation initiatives have been already planned to confirm/reject the mentioned hypothesis.

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