LCA (Life Cycle Assessment)

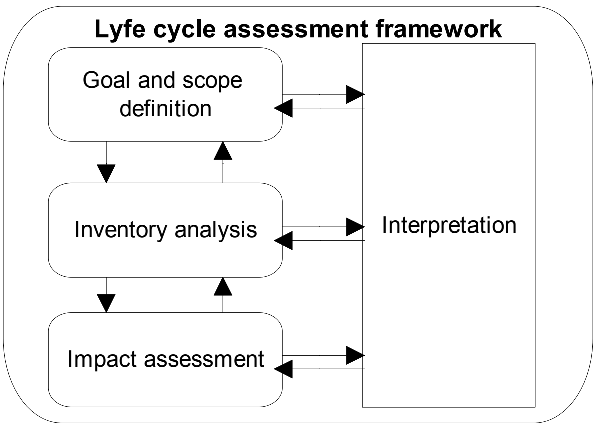
The life cycle assessments conducted on the industrial districts of Prato, Lucca and Pistoia represent the first time the analysis model has been applied to an articulated manufacturing system such as the industrial district.

The LCA makes it possible to:

- quantify the environmental impact of complex industrial chains by following a rigorous, scientific method;
- take into account the environmental and energetic aspects related to the production of raw materials and the "destiny" of the industrial sites' co-products;
- coherently compare alternative industrial systems.

The LCA is a tool for the quantitative assessment of the environmental and energetic benefits associated with the possible options for recovering wastes produced by the three districts considered in the project (paper, textiles and plants).

The LCA consists of a "cradle to grave" calculation of all raw material and energy consumption along with all emissions into the air, water and solid wastes from the manufacturing chain. It covers all phases of the life cycle, from raw material extraction to final disposal.
First of all we obtain an **inventory** (Life Cycle Inventory or **LCI**) of inflow (consumption) and outflow (emissions) from the system along the entire life cycle. These flows are also known as impact factors.
Then, by assigning weights (as published by competent international bodies) to the inventory impact factors, we calculate the system's contributions to the various types of environmental impact (Impact Assessment): Greenhouse Effect, Acid Rain,



Consumption of Non-Renewable Resources, etc..
As we can see from the previous diagram , conducting a Life Cycle Assessment as set forth in ISO 14040 is an iterative process.

Prior to drafting an eco-balanced sheet we must define the principal elements of the task and:

- define the objectives
- select a functional unit
- outline the field of study.

The choice of the functional unit and field of study are contingent upon the objective to be reached. The comparative analysis of two products for example, requires an accurate definition of the function that links each of the products to the same use and to an objective comparative base without any ambiguity whatsoever. For the same reason, the outlining of the systems taken into account must be homogeneous among the various products/systems studied. It is theoretically impossible to assess all the impact factors related to a given activity or product. In practice, the choice of the functional unit and systems studied favors the most significant phases of the life cycle under consideration in terms of environmental impact.
Within the framework of the CLOSED Project, the Life Cycle Assessment was conducted by taking into account three different options for environmental improvement that are specific to each district, and they are listed below.

PISTOIA

a) Reutilization of the soil removed from sold plants as soil for new crops.
b) Reutilization of waste plants as compost for new crops.

a) Reutilization of the soil removed from sold plants as soil for new crops.

Part of the soil used for growing the plant is kept from the plant itself. The remainder is currently sent to a dump as inert waste. One hypothesis for reutilization calls for using this part of the soil for subsequent crops. The recovered soil replaces the following raw materials:

- Peat
- Pumice
- Bark
- Coconut fiber

The amount that can be recovered has been estimated at 200 kg of soil per hectare per year of cultivation.

b) Reutilization of waste plants as compost for new crops

The rejected plants are currently sent to the dump. One hypothesis for reutilization calls for grinding them and then using them as compost for subsequent crops. In the recovery scenario we assume that all the plants rejected annually in the district be reused in this way.

LUCCA

Energetic recovery of “pulper waste” (consisting of packing materials separated from the waste paper used as a secondary material for the production of recycled paper).
Pulper waste has a lower heating power of approximately 4,750 Kcal/kg dry which makes it a sufficiently adequate fuel for the production of heat to reuse within the same paper manufacturing chain as described below.
In view of the considerable amount of sludge produced in paper mills, the hypothesis is to use the pulper waste combustion fumes for a sludge dryer that is more “powerful” than the ones currently in use, to achieve a 50% moisture level as opposed to the mean current level of 70%.
This would make it possible to reduce the weight of the wastes sent to final disposal with a consequent economic and environmental savings for the transportation phase.

PRATO

Reutilization of the waste flock (the textile waste that is less than a few millimeters long even if this parameter is not binding) as fuel through burning with a cogeneration

energy recovery. This makes it possible to recover part of the electrical energy needed for textile production.
The amount of waste flock available in the entire Prato district comes to 27,405,000 kg that is equal to 15% of total annual textile production.
The only problem related to the use of waste flock as fuel is the PCI (lower heating power) value that is relatively low and therefore, inevitably reduces the scenario's environmental advantages.

The data were obtained from questionnaires – that were differentiated for the individual districts. The following table shows the descriptive elements for the LCA by district.

District	Companies interviewed	Phases of the process studied	Functional unit	Production parameters
Lucca	13	Tissue production, Testliner, fluting, corrugated cardboard and packing cardboard production	Tons of paper or cardboard produced	1,000,000 t of tissue 900,000 t of testliner and fluting 100,00 t of corrugated cardboard
Pistoia	18	Fullfield and potted crops	Hectares of cultivated land	4,200 fullfield ha. 680 ha. of potted plants
Prato	16	Sorting, spinning, twisting, purging, dyeing and finishing	Kilos of product processed	426 million meters of fabric

The objectives for environmental improvement studied with the LCA method are essentially:

a) material recovery
b) energy recovery

In case (a) we considered the reutilization of some types of materials exiting the plants within the same manufacturing chain (both as the individual company and the district). We did not consider possible recycling that involve reprocessing the waste prior to reutilization.
In case (b) we examined reutilization scenarios for two of the three districts (that are described in more detail below). The energy flows are grouped as follows:

Total Primary Energy: the source of all energy sources that are directly extracted from natural reserves such as natural gas, oil, coal, biomass and hydroelectric energy.
Total primary energy is calculated from the following parameters:

- lower heating power (PCI) for fossil fuels and biomass
- potential gravitational energy for hydroelectric energy
- the rate of depletion of nuclear fuels

Other energy sources, (wind, sunlight, etc.) are negligible within the context of this study.

Total primary energy can be broken down into renewable and non-renewable energy, or into fuel and feedstock energy.

The equation below illustrates the foregoing

Primary total energy = Non-renewable energy + renewable energy = Fuel Energy + Feedstock Energy

Non-renewable energy: includes all fossil and mineral sources of primary energy such as oil, natural gas, coal and nuclear energy.

Renewable energy: includes all other sources of primary energy, mainly hydroelectric and biomass.

Fuel energy: corresponds to the portion of the primary energy that enters the systems and which is consumed by processes within the confines of the system itself (e.g. burning natural gas).

Feedstock energy: corresponds to the portion of primary energy contained within the materials that enter the system and which is not consumed in the system as fuel (e.g. wood used in paper manufacturing).

In order to define the environmental improvement options for the three different manufacturing sectors we have determined the main chemical-physical parameters to take into account when evaluating environmental impact as well as some parameters related to the assessment of comparative scenarios from the standpoint of reducing produced wastes.

District	**Material**	**Chemical-Physical Properties**	**Assessment Elements**
Prato	Textile waste flock	Fossil C: 49.27% dry H: 6.46% dry O:3.18% dry Cl: 39.98% dry S: 0.21% dry Mineral materials: 5.63% dry Rfe: 0.24% dry Al: 0.17% dry Density: 100 kg/m^3 Moisture: 19% Lower heating power (PCI): 18.28 MJ/kg dry	The mean distance between the plant and the incinerator facility has been assumed to be 50 km.
Lucca	Pulper waste	Fossil C: 47.89% dry H: 7.56% dry O: 39.39% dry Cl: 0.7-1.25% dry (*mean value*	The mean distance to combustion was assumed to be 50 km. The mean distance from the plants to

		obtained from a chemical analysis of pulper waste) Cl: 3.25% dry (*maximum value obtained from a chemical analysis of pulper waste)* S: 0.53% dry (*mean value obtained from a chemical analysis of pulper waste)* Mineral materials: 8.5% dry (*mean value obtained from a chemical analysis of pulper waste)* Fe: 0.33% dry Al: 0.019964% dry (*mean value obtained from a chemical analysis of pulper waste)* Density: 100 kg/m^3 Moisture: 56.6% lower heating power (PCI): 19.9 MJ/kg dry (*mean value obtained from a chemical analysis of pulper waste)*	disposal was assumed to be 200 km (actually it varies from 100 to 300 km). Energy consumption required for drying: energy required for 1 kg of sludge: [540+(100-20)]/0.56 in kcal. - latent heat of water vaporization: 540 kcal/kg - - specific heat of water: 1 kcal/kgC - -drying process yield: 0.56
Pistoia	Soil		The logistics of virgin soil procurement are broken down by component as follows: - peat: 2500 km for 80%; 1000 km for 20% (*hypothesis: rail transport)* - Pumice: 500 km by ship + 100 km by truck - Bark: 950 km *(hypothesis: rail transport)* - Coconut fiber: 20,000 km by

			ship + 100 km by truck We also assumed that the soil would be reused by the companies where it is produced as waste (distance to reutilization = 0).

Assessment of the life cycle's environmental impact
The data analysis was done using certain reference parameters on the basis of which we can assess not only the environmental impact of the district's mean product life cycle and its trend, but also the impact of new technologies or new products in an environmental benchmarking of the product.

We used the following analysis indicators (that is both environmental impact indices and inventory flow):

- Total Primary Energy
- Consumption of non-renewable resources (CML)
- Greenhouse effect (direct, over 100 years) (IPCC)
- Acid rain (CML)
- Creation of photochemical oxidants (WMO)
- Diminishing ozone layer (WMO)
- Water eutrophization (CML)
- Human toxicity (CML)
- Total wastes
- Hazardous wastes

The investigated parameters are the basis for a brief assessment that is the fundamental element for determining whether the direction of a change goes towards reducing impact or the other way.
The hypothesized changes refer to environmental impacts evaluated starting from the scenarios we obtained from the analyses.

The impacts were reviewed starting from a breakdown among the three districts.
In this way we were able to see the different environmental weights:

- of the three districts;
- of the various phases of the production chain;
- of the different productive volumes.

The intrinsic pollution of each individual district is difficult to evaluate through this analysis which does, however, permit an overall assessment of environmental impact of the ecosystem and on the territory of the three districts.

THE ENVIRONMENTAL IMPACT ANALYSIS

A) Energy and non-renewable resource consumption

The analysis of energy and non-renewable resource consumption reveals which phases in the three districts contribute most to those indicators.

The first finding relative to the three districts shows that the 88% of the energy consumed in all three is used in Lucca (approximately 61% in phase 4 of the Paper Tissue process and 44.9% from the fuel used in that phase); of the remaining energy consumption approximately 8.65% can be attributed to textile manufacturing from the purging to the dyeing/finishing processes (phase 7).
The analysis of **non-renewable resource consumption** gave entirely similar results since energy consumption is the main factor (83.6% attributable to tissues/Lucca; and 12.4% from Prato).

B) Impact on the atmosphere
Regarding the three districts' contribution to the **greenhouse effect**, once again Lucca is responsible for 76.3% of the emissions from the three districts (about 50.2% can be attributed to phase 4 of the paper tissue process). The main reason is that the highest portion of carbon dioxide and methane emissions come from this phase.
It is sufficient to mention that CO2 accounts for 89% of this total impact in the area and that the remaining 10.3% percent is linked to methane emissions.
The contributions (roughly 26%) related to testliner fluting for paper manufacturing are also significant.
The overall contribution from the Prato district (equal to 19.65%) to this impact category is linked to phase 7 (purging to dyeing/finishing for textiles).

The situation concerning the effects of **photochemical pollution** are slightly different. Here the contribution from the district of Lucca is equal to 54.6% (37.1% related to tissue production, while the contribution from Prato is slightly more than 40% (phase 7).
In this case we can state that in the two districts two different substances contribute to the overall environmental impact. In Lucca it is caused almost exclusively by hydrocarbon emissions, while in Prato it is due to COV emissions.
The "**destruction of the ozone layer**" effect comes from the Lucca district, and that is 82.51% (with nearly 27.8% linked to testliner fluting for paper) and roughly 13.45% comes from the Prato district.

C) Impact on water
The **eutrophization** effects come almost exclusively from the paper manufacturing district and are broken down with greater "equilibrium" within the system: nearly 44% is related to testliner/fluting, 18% to the tissue phase, 30% to the water treatment system, which inevitably tends to "concentrate" the formation of this impact subtracting it from other phases (but that is precisely the role of a purification system).

D) Human toxicity
Insofar as the analysis of the **human toxicity** indicator is concerned, we can say that, taking the district as a single whole, it depends essentially on the emissions of four substances:

- nickel, that accounts for 10.7%;
- nitrogen oxides, that account for 29%;
- sulfur oxides that account fro 59.4%
- vanadium that accounts fro 8.6%.

The contributions of the various districts to the overall impact depends on the breakdowns of how these substances are emitted.
The district of Lucca accounts for 81% of total human toxicity (25.4% for the testliner/fluting phase, 55.4% for tissue). In the Prato district (that accounts for 15.27% of the total) phase 9 is also a contributor (20.5%) (in this phase the textiles, i.e. yarns, go from twisting to weaving).

E) Waste production
The situation is quite different when it comes to total waste production in the three areas (one of the most significant aspects of the CLOSED Project).
Given 100 as the total amount of waste produced by weight, origins are broken down as follows:

- 72.1% from the Lucca district (45.9% from testliner/fluting, 21.2% from tissue, 5% from the purification plant) consisting essentially of pulper waste and bark;
- 22.4% from the Prato district (13.4% from dyeing/finishing, 4.5% from sorting/spinning, 4.6% from twisting/weaving), consisting of waste textile fibers and packing materials;
- 5.23% from the Pistoia district (waste/rejected plants).

The situation concerning hazardous waste production in the three areas is somewhat different.
In this case taking 100 as the benchmark total of hazardous wastes produced by weight, origins are broken down as follows:

- 55.2% from the Lucca district (12.4% from testliner/fluting, 42.7% from tissue, almost nothing from the purification plant) consisting essentially of oils, oily dregs, emulsions and batteries/accumulators;
- 36.08% from the Prato district (35.1% from dyeing/finishing, the remainder from sorting/spinning and twisting/weaving), consisting of oils and sludge;
- 8.74% from the Pistoia district.

VERIFYING THE HYPOTHESES FOR WASTE REUTILIZATION

The districts' reutilization scenarios were not defined purely on the basis of environmental considerations. Rather we considered scenarios that would lead to improvements in the use of invested economic and technological resources, based on proposals from the Industrialists' Associations, to ascertain that these scenarios would not increase the environmental impact.
The variations are negligible for most of the indicators analyzed.
The only significant variations concerned total waste production (with a 15% decrease with respect to the current scenario) and hazardous waste production (doubled in quantity with respect to the current situation).
The decrease in total waste is due to the reutilization of production wastes in the three districts as described. The increase in hazardous wastes is due to the incineration of pulper waste (paper district) and of the recovered waste flock in the textile district. The incineration plant produces hazardous wastes.
We must, however, keep in mind that the increase in hazardous waste production in the reutilization scenario is significant in relative, but not in absolute terms (while an incinerator produces unburned cinder that is classified as hazardous wastes, the production chains of the three districts do not produce major amounts of hazardous wastes, hence the striking percentage increase).

The first conclusions of the life cycle assessments reveal three elements concerning the study districts:

a) the recovery scenario for the Prato district is environmentally sound even if this soundness is moderated by the choice of waste flock as the combustion material. This material has a low PCI and energetic exploitation reflects this choice. When creating the eco-industrial district the choice may actually go to the recovery of production wastes that yield greater environmental advantages. However, it is certain that if the choice were to fall only on waste flock, the processes would yield environmental advantages but not to any extent that would justify the building of an ad hoc incinerator.
b) the recovery scenario for the Lucca district, constructed on the basis of greater economic advantages explored the possibility of using "pulper waste" from the energy standpoint, using the combustion fumes from the pulper waste for more "aggressive" sludge drying to reach a moisture level that is roughly 10 percentage points lower than the current one of 70%. This would make it possible to reduce the weight of the wastes sent to disposal, with a consequent economic and environmental savings in the transport phase. Along the life cycle the results of this scenario did not worsen the environmental situation with respect to the current situation. However, other solutions would have to be sought in order to achieve environmental savings.
c) Like the foregoing this scenario did not worsen the environmental situation:
   - reutilization of soil discarded from sold plants as basic soil (compost) for new crops;
   - reutilization of waste plants as basic soil (compost) for new crops.

   The results of this scenario, like the preceding one, did not worsen the environmental situation. However, other solutions would have to be sought in order to focus on environmental savings. The center for eco-industrial symbiosis would have to explore other, more environmentally advantageous, roads.