DESERESCUE

Small agro energy farm scheme implementation for rescuing deserting land in small Mediterranean islands, coastal areas, having water and agricultural land constraints. Feasibility study.

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0. THE PARTNERSHIP

The DESERESCUE research group was composed by ETA (I), ITER (ES), CENET (D) and IFP (D).

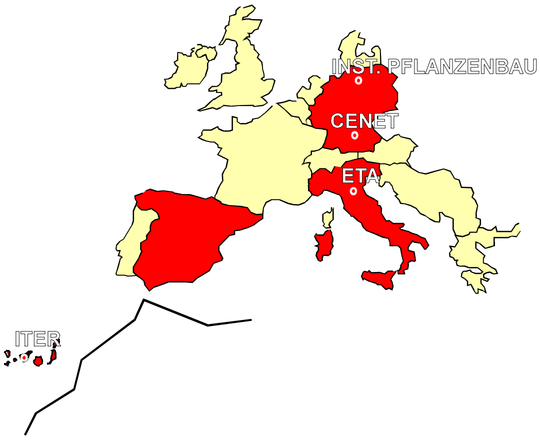

Fig. 0.1 – The parnership

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1. OBJECTIVES OF THE PROJECT

The term desertification immediately prompts an image of regions with serious land damage problems or with difficult life conditions. The land degradation is due to climatic variations and human activities. It is also generally recognised that the human factor is less important than the climatic variations: in fact, the temporal and spatial variability of precipitation is one of the intrinsic characteristics of drylands which influence the process of land degradation. Today desertification is preoccupying scientist and policy makers in many Countries.
The 1992 UN Conference on Environment and Development held in Rio de Janeiro, defined the word desertification as: “the land degradation in arid, semiarid, and sub-humid areas resulting from various factors including variations and human activities”. Approximately one third of the earth’s land area and as many as 850 million people are at risk: UN studies claim that no less than 29 per cent of the land surface now suffers from slight, moderate or severe desertification, and a further 6 per cent is severely desertified. In 1984 some 230 million of the 850 million people who lived in the world drylands were estimated to be suffering from the effects of severe desertification. No less than 18.5 per cent of land in South America, Asia, Africa and in the Mediterranean Area is now severely desertified.
It has been observed that erosion threatens more than the 50 % of agricultural lands in the Mediterranean area. In Southern Europe 60 % of the land is threatened by desertification, including Central and Southern Italy, Central and south-east Spain, Southern France, Southern Portugal, Sardinia, Crete and extensive area of Greece. The problem is getting worse. In spite of attempts both by individual countries and by international agencies, the relentless march of the desert cannot apparently be halted. More than 20 million hectares of land become so desertified every year that agriculture becomes uneconomic. Some 6 million hectares are permanently degraded to desert every year.

The aim of this project is to show how and at which cost the start of new life in arid or deserted coastal areas can be originated by the introduction of a simple bio-energy scheme.
The main objective of this project was therefore to implement a techno-economic evaluation of a full bioenergy project for the reconstruction of an artificial good quality soil in a deserted coastal area of the Tenerife island for the production in sequence of biomass (herbaceous crops), electricity / heat and desalinated water by reverse osmosis (RO), needed for irrigation and other uses. Biomass productivity in these extreme conditions has also been estimated, including the possibility of CO_2 injection and the use of high water retention crystal grains in the artificial soil. Finally, the electricity and desalinated water cost were evaluated, as well as the total investment cost.

2. TECHNICAL DESCRIPTION

2.1 METHODOLOGY

As already mentioned, the scheme proposed by the DESERESCUE project is a new sustainable approach to fight desertification, showing how and at what cost starting new vegetal life in arid or deserted coastal areas can be achieved by simple bio-energy schemes. Soil is reconstructed through a mixture of local poor soil and organic compost from Municipal Solid Waste (MSW).
An advanced small size power plant (few hundreds kWe) based on biomass solid, liquid or gaseous fuel can generate electricity for operating a desalination plant: the desalinated water produced will be used for irrigation, but some energy/biomass/water surplus will be available for other uses.
The project was based on reliable and commercially available technologies as such only technologies capable of assuring sufficient reliability and long-term operation, in order to create a sound scenario that - at least from the energetic point of view - could be today successfully

implemented. Therefore, after an initial study on both biomass production in arid lands as well as available technologies, a preliminary balance of the biomass-energy-water production cycle was performed and subsequently refined as more detailed data were collected.
In the present work only deserted areas located near the sea are considered, in order to have access to sea water supply for the desalination plant. The existing link between water resources, population needs and land use (full operative working scheme) is presented in fig. 2.1:

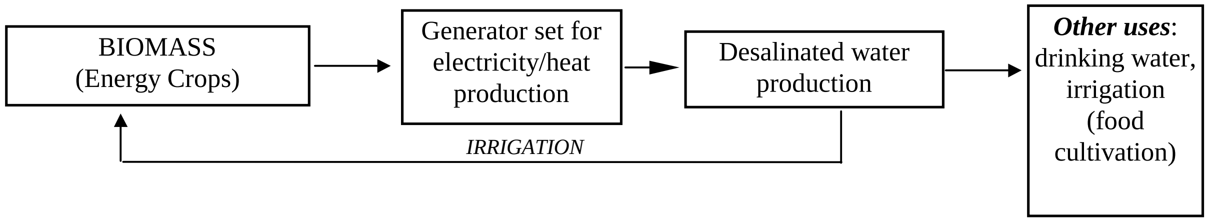

Fig. 2.1 - Bioenergy complete scheme

The methodology adopted to perform this feasibility study is reported in the following scheme:

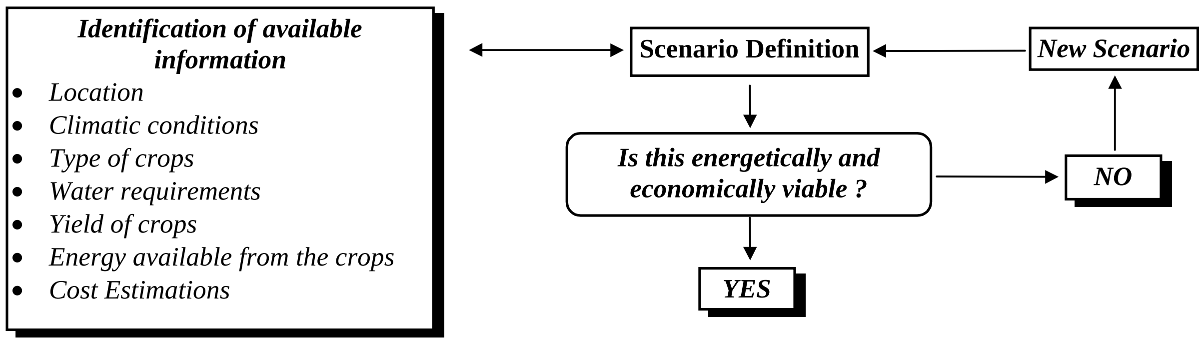

Fig. 2.2 - Scenario definition path

The project was divided into three main phases:

- *preliminary feasibility study*, where the most important aspects, such as biomass yield, technological options, local conditions, etc. are defined and collected
- *detailed design study*, aimed to identify a detailed scheme of all susbsystems (biomass choice and cultivation, energy and water production)
- *final techno-economic assessment of the full system*, defining a specific possible solution for the island Tenerife and suggesting general recommendations for the design of such systems.

Therefore, after the definition of different options/scenarios during the pre-feasibility phase of the study, a more detailed evaluation on how to reach a completely self-sufficient system in terms of energy and desalinated water demand/production was performed. It required a deeper analysis of several aspects, such as soil and crop characteristics, existing technological options for energy production from biomass, existing desalination and irrigation systems, and so on.
The study was aimed to analyse a 10 ha area. The research activity covered four main items: biomass production

- power generation
- desalinated water production
- irrigation

A complete biomass-power-desalination system was defined, as reported in the following scheme.

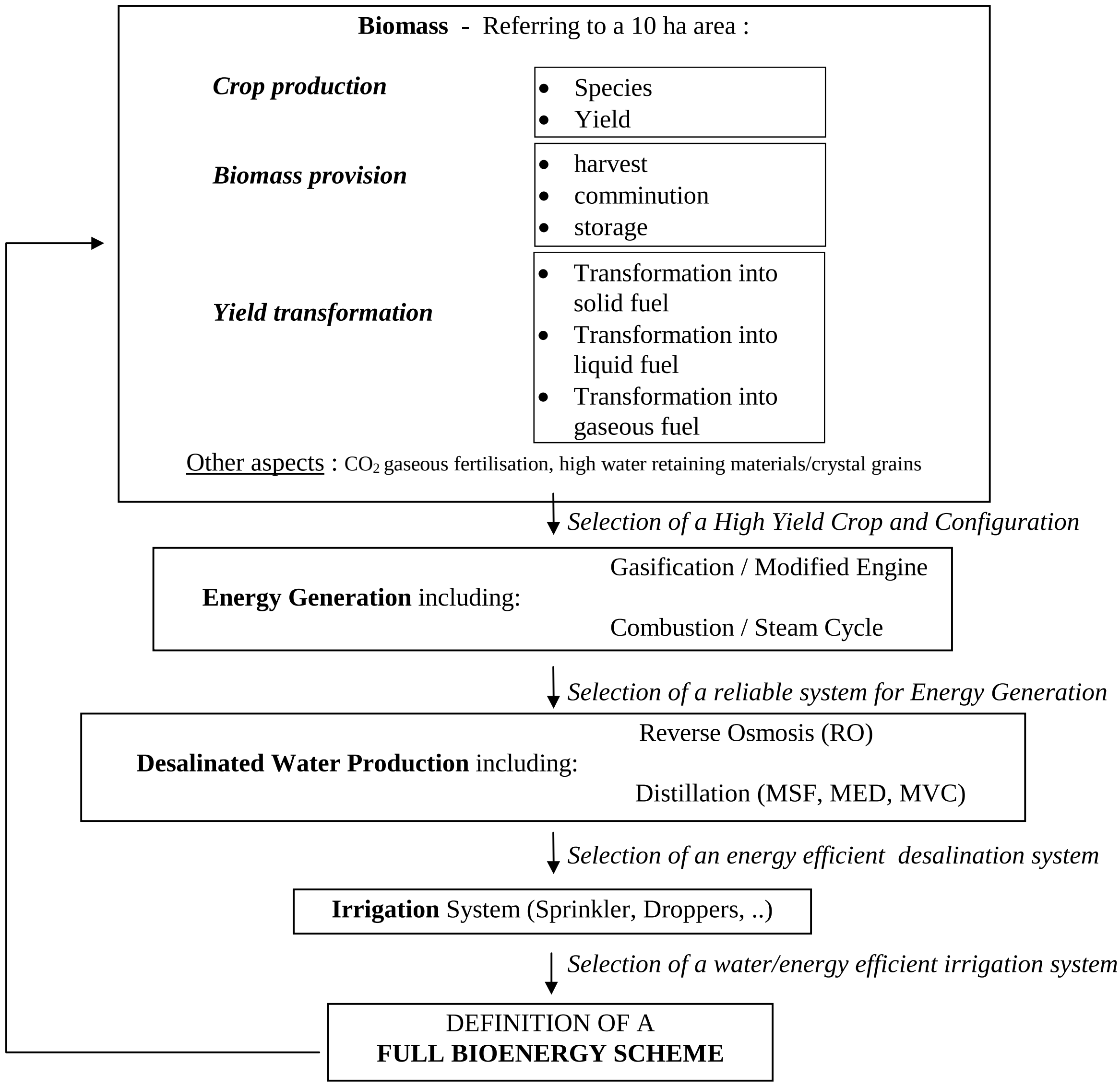

Fig. 2.3 - Project flow-chart

A possible example of fresh water production from bioenergy (at small scale capacity) is reported here below.

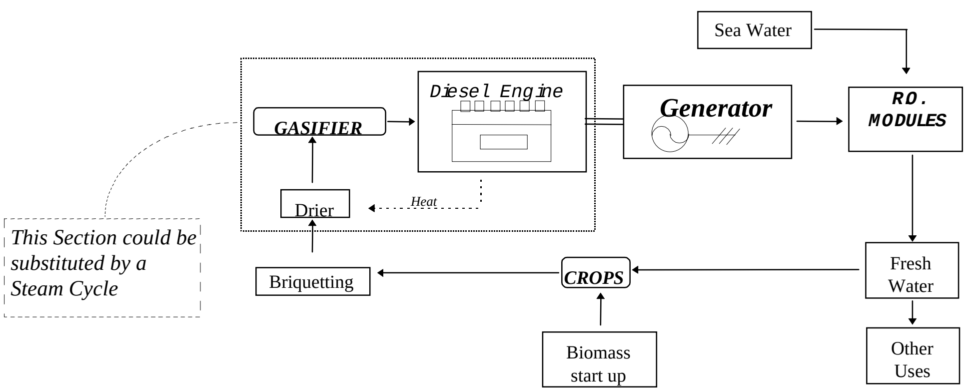

Fig. 2.4 - A full bioenergy/desalination scheme as proposed by the DESERESCUE project

3. RESULTS AND CONCLUSIONS

3.1 SUMMARY OF THE MOST IMPORTANT RESULTS

The most important aspects considered by the present project are summarised here below:

Tenerife climatic conditions: local climatic conditions in the southern part of Tenerife have been analysed and considered for the implementation of the project on a 10 ha area.
The average yearly temperature is approx. 21.4 °C, showing a smooth variation (approx. 7°C during the year). Average yearly precipitation is approx. 140 mm, while average wind speed is between 7.5 and 8.9 m/s. The average number of insulation hours is approx. 2,708 hours/year.
Local Vegetation: local natural vegetation has been studied.
Site selection: An appropriate site was selected as a reference case study: a very arid area (10 ha) in the Southern of Tenerife was chosen. The soil which is available within this area is considered to have the lowest potential in the island.
Soil characterisation: data concerning local soil characteristics have been collected.
Compost composition: compost obtained from MSW available in Tenerife was characterised.
Analysis for soil reconstruction: methods and costs for artificial soil preparation (mixture of local soil and compost) were analysed and described.
The artificial soil reconstruction cost per m^3 (considering machinery, transportation, staff and compost costs) is reported in the following table:

	ECU/m^3
Machinery	6.00
Transports	0.73
Staff	0.25
Compost	13.46
Total	20.44

Table 3.1- Artificial soil production cost in Tenerife

According to these values, the cost in Tenerife for reconstructing a 10 ha area by means of 80 cm thick artificial soil is considerable: in fact, being approx. 80,000 m^3 of artificial soil needed, a total cost of 1.635 MECU is calculated. However, considering the specific characteristics of the land in Tenerife, a more reasonable estimation could be the reconstruction of a 40 cm thick artificial soil: it therefore would reduce the total cost for the 10 ha soil preparation to approx. 817 kECU.
Water retaining crystal grains: characteristics and costs of these high water retaining grains, including other similar low cost materials (e.g. pumice stone), were considered,
Crop selection: energy crops having low water input and suitable for the cultivation in these arid lands were considered. Sweet Sorghum was considered very suitable to the DESERESCUE scheme.
Salt resistant crops: other very interesting crops, potentially suitable for start-up purposes and accepting salt water for irrigation (such as *Salicornia bigelovii*), were analysed and described.
Production and provision of biofuel: possible methods for the production and provision of the biofuel were analysed. A costs estimation was also performed.
CO_2 Gaseous fertilisation: The effect of CO_2 gaseous fertilisation was also assessed: biomass yield can be increased up to a maximum of approx. 2.9 times the amount of usual cultivation.
Evaluation of contaminants in the artificial soil: the effect of contaminant removal was analysed and defined.
Biomass power generation system: As far as concern the biomass power generator, the analysis was

initially based on a commercially available 100-400 kW_{el} gasifier (European technology). However, although economically competitive, some major constraints against its utilisation in this specific context were found. In particular: not sufficient reliability in case of bioenergy schemes based on energy crops (reliable operation only in case of wood), need for biomass drying, and, finally, need for biomass compacting (such as briquetting, energy consuming).
In parallel with gasification technology, combustion technologies were also investigated during the project: within the limited number of the commercially available small capacity biomass power generators, a feasible solution was found on the basis of very recent EU technology. A biomass system producing in the range of 400 kW_{el}-1200kW_{th} / 500 kW_{el}-2000kW_{th} was finally selected for the project (guaranteed life > 20 years).
Desalination system: An investigation of desalination systems was undertaken: Reverse Osmosis was chosen as the best performing sea-water desalination system. In parallel, brackish water desalination systems were considered from the energetic as well as the economic point of view: these systems are very interesting for the proposed scheme, and could greatly improve the balance of the overall system. However, in order to ensure relevance to all situations, less favourable scenarios were considered, and hence only sea water desalination was examined.
Irrigation system: drip irrigation was considered as the most appropriate in the selected environment: therefore complete drip irrigation system was also assessed.
Measuring and control system: a control system was included in the system configuration.
Bioenergy scheme start-up aspects: start-up aspects have been analysed, describing the different options (e.g. diesel engine or use of salt resistant crops)
Tests at ITER: Some small tests (100 m^2 area) were also performed in the selected location of Tenerife: several crop cycles were cultivated on the artificial soil (pure mixture of local soil and compost, no additives or fertilisers - excluding high water retaining materials) under study. A complete RE (PV) powered system was arranged for irrigation purpose: water was desalinated by means of an already existing small scale plant. The aim of these test was :

- to compare different crops in the chosen arid area
- to verify the adaptability of Sweet Sorghum to local climate and environment.

It was experimentally verified that also in these extreme conditions Sweet Sorghum is capable of growing: even in case of no irrigation water during some days, Sweet Sorghum survive. Moreover, the wind effect on plant growth was found to be more important than was initially estimated.
Techno-economic assessment of the entire system and cost of the products: a complete techno-economic assessment was finally performed for the chosen configuration.
The energy surplus was estimated to be in the range of approx. 18-28 %, which could be seen either in terms of biomass or energy or water.
The manufacturers of the main components (biomass generator, desalination system, irrigation system) provided formal offers for their products: therefore, a techno-economic assessment for the complete system was performed. The production costs of biomass, electricity and water (and therefore the irrigation costs) were assessed.
The economics of the whole system were restricted, mainly due to the current high cost of the biomass power generator, resulting in a high production cost for the biomass (from 1500 to 3500 ECU/t_{DM} depending on the economic calculation mode). Therefore, the cost for biomass irrigation by desalination plants powered by fossil fuel in a standard diesel engine was also evaluated: these results showed considerably less, however still significant costs (550 ECU/t_{DM}). As a final conclusion, the system can be regarded as energetically balanced but still economically to be improved. Therefore, some possible methods for improving the economics of the whole system were identified.

Land rescuing potential and scale-up for the proposed scheme: the land rescuing potential (the main goal of the project) of the proposed 10 ha bioenergy scheme, as well as a scale-up of the system, were described.

The most relevant result of the project is probably represented by the fact that the proposed scheme is energetically balanced and feasible using commercially available technologies only.
A more detailed description of the most important items follows.

3.1.1 Biomass selection

Sweet Sorghum was selected as a suitable very promising cultivation for this type of application, being very efficient in both terms of water use and yield. Only bagasse was considered in the calculations: an average yield of 28 t_{DM}/ha/y has been considered feasible on the basis of a single crop cycle (if sufficient amount of water, approx. 190 l/kg_{DM}, is available for irrigation). However, this type of energy crop is also very interesting for further improvement of the system, being capable of producing other biofuels (as bio-ethanol) in scaled-up systems.
In the number of salt resistant crops, a very promising crop is *Salicornia bigelovii*: it can endure salt concentrations up to 50,000 ppm (5%) without blighting. Though the salt build-up can be harmful, it can be avoided by overwatering. On survey plots in Mexico, *S.bigelovii* finished in the top five of halophytes for dry weight (dw) productivity in a one year trial (see next tab. 3.2).

Plant	**Productivity (t dw/ha/y)**
Atriplex lentiformis	17.94
Batis maritima	17.38
Atriplex linearis	17.23
Salicornia bigelovii	15.39
Distichlis palmeri	13.64

Table 3.2 - Halophytes productivity

At the same location in Mexico, after 6 years of trials *S.bigelovii* showed a mean biomass yield of 20.2 t/ha/y and a mean seed yield of 2.03 t/ha/y.
Costs for cultivation have also been collected: however, this crop (that could be used for start-up the system) needs deeper investigation in EU through trials and experimentations.

3.1.2 Power Generator

The proposed scheme was initially based on gasification: therefore, a small scale (from 100 to a maximum of 600 kW_{el}) system was initially considered and taken as reference for the present study. This unit was analysed in terms of technical characteristics, energy production and economics, and a formal offer was provided by the manufacturer.
However, being the proposed project aimed to propose a sound solution feasible today on the basis of commercially available technologies, some additional aspects concerning the reliability of the system have been considered.
In particular, while the performances of this type of generator are guaranteed (8000 h/y, 10 years of operation if a scheduled preventive maintenance program is implemented) in case of wood fuel, less reliability is expected if energy crops are used in the place of wood. Moreover, briquetting (or similar biomass compacting system) and biomass drying below 16-20 % moisture content are required, affecting the overall energy balance of the complete and therefore reducing the sustainability of the proposed approach.
On the basis of thes aspects, the research group considered the possibility to improve the reliability of the scheme using a biomass combustion system instead than gasification. Several small scale systems are today available on the market: however, these are extremely low efficient (approx. 7%) and very expensive. As a consequence, these units are not appropriate for the DESERESCUE scheme: they are usually considered only when huge quantities of zero-cost biomass residues

(mainly wood) are available on the site.
A research aimed to identify on the EU market new products in this sector was therefore implemented during the project: a brand new turn-key Combined Heat and Power (CHP) plant was found in Sweden, having an average electrical efficiency of 20-25 % (variable with the heat use), power production of approx. 400-500 kW_{el} (1200-2000 kW_{th}), and accepting biomass at very high humidity (from 7 to 60 %).
Therefore, considering all these aspects, and aiming to design the most reliable bioenergy scheme as possible today, this combustion system was preferred to gasification for the project. Summarising, this choice assure the following main advantages:

- Continuous operation of the system guaranteed for more than 20 years
- Good performances (η_{el} in the range of 20 - 25 %)
- No need for drying system (biomass humidity from 7 to 60 %)
- Wide possibilities of regulation (from 200 to 500 kW_{el})
- Possibility of adding any kind of available agriculture residues as useful fuel

3.1.3 Desalination system

In the range of the many different solutions available on the market, Reverse Osmosis (RO) was selected as the most energy efficient system (~ 5 kWh/m^3 of desalinated water) at small scale production level for sea water desalination. Moreover, its modularity makes the system very flexible. Calculations have been perfomed on the basis of sea water, in order to design the proposed scheme under the most difficult conditions. However, in case of availability of brackish water, Electrodialysis (ED) can also be considered instead of RO.
A summary of the average energy consumption per state-of-the-art technology is reported in the following table.

PROCESS	ELECTR. ENERGY EQUIV. CONSUMPT. (kWh_{el}/m^3)
Seawater	
MSF	10 - 14.5
MED	6 - 9
VC	7 -15
SWRO	4 - 8
Brackish	
BWRO	0.5 - 2.5
ED	0.7 - 2.5

Table. 3.3 – Desalination energy consumption (Source IPTS)

3.1.4 Gaseous (CO_2) fertilisation

The effect of gaseous fertilisation on energy crops and, in particular, on Sweet Sorghum, has also been assessed. Sweet Sorghum yield was found to increase up to 2.9 times the reference value of usual cultivations. However, this type of fertilisation can not be easily implemented, being necessary a greenhouse. Due to the high cost of the greenhouse, the proposed scheme did not consider the use of such structure and, therefore, gaseous fertilisation was not included in the final scheme elaborated by the research group. With regard to the methods for CO_2 fertilisation, 2 methods are possible to enhance the CO_2 concentration in the vegetation atmosphere up to 1000 ppm CO_2:
- Liquid CO_2 sources
- Combustion of natural gas, propane or butane to produce CO_2 and then its infusion into the

greenhouse.
The cost of CO_2 is approximately 0.50 ECU per kilogram. Table 3.4 summarises the effects of elevated CO_2 concentrations on several plant species.

Crop type	**Crop**	**Enhanced CO_2 Mean relative yield increase**	**Sensitivity of enhanced UV-B**	**Sensitivity to O_3**
Fiber crops	cotton	3.09	tolerant	sensitive
C4 grain crops	sorghum	2.98	sensitive	intermediate
Fiber crops	cotton	2.59-1.95		
Fruit crops	eggplant	2.54-1.88	tolerant	unknown
Legume seeds	peas	1.89-1.84	sensitive	sensitive
Roots & tubers	sweet potato	1.83	unknown	unknown
Legume seeds	beans	1.82-1.61	sensitive	sens./intermed.
C3 grain crops	barley	1.70	sensitive	tolerant
Leaf crops	Swiss chard	1.67	sensitive	unknown
Roots & tubers	potato	1.64-1.44	sens./toler.	sensitive
Legume crops	alfalfa	1.57	tolerant	sensitive
Legume seeds	soybean	1.55	sensitive	tolerant
C4 grain crops	corn	1.55	tolerant	sensitive
Roots & tubers	potato	1.51		
C3 grain crops	oats	1.42	sensitive	sensitive
C4 grain crops	corn	1.40		
C3 grain crops	wheat	1.37-1.26	tolerant	intermediate
Leaf crops	lettuce	1.35	sensitive	sensitive
C3 grain crops	wheat	1.35		
Fruit crops	cucumber	1.30-1.43	sensitive	intermediate
Legume seeds	soybean	1.29		
C4 grain crops	corn	1.29		
Roots & tubers	radish	1.28	tolerant	intermediate
Legume seeds	soybean	1.27-1.20		
C3 grain crops	barley	1.25		
C3 grain crops	rice	1.25	sensitive	intermediate
Fruit crops	strawberry	1.22-1.17	unknown	tolerant
Fruit crops	sweet pepper	1.20-1.60	sens./toler.	unknown
Fruit crops	tomato	1.20-1.17	sensitive	sens./intermed.
C3 grain crops	rice	1.15		
Leaf crops	endive	1.15	unknown	intermediate
Fruit crops	muskmelon	1.13	sensitive	unknown
Leaf crops	clover	1.12	tolerant	sensitive
Leaf crops	cabbage	1.05	tolerant	intermediate
Flower crops	nasturium	1.86		
Flower crops	cyclamen	1.35		
Flower crops	rose	1.22	tolerant	
Flower crops	carnation	1.09		intermediate
Flower crops	chrysanthemum	1.06	tolerant	intermediate

Table 3.4 - Comparison of sensitivities of agricultural crops to enhanced CO_2, (mean relative yield increases of CO_2-enriched to control) for CO_2 concentrations of 1200 µL/L or less, or 680 ppm; to enhanced UV-B radiation; and to ground-level O_3. (1 µL/L or 1 ppm CO_2 = 1.008 µmol mol^{-1} at STP).

3.1.5 Crystal Grains

The use of high water retaining crystal grains was also assessed. Data concerning technical characteristics, availability and costs have been collected and defined: the cost for including these crystal grains within the artificial soil on a 10 ha area has been estimated approx. 38,000 - 152,000

ECUs. However, an average cost of 10,000 ECU/ha could be positively considered because the amortisation time of this investment aimed to rescue arid lands can be extremely long (e.g. 50-70 years): therefore, this long term advantages can justify the adoption of these crystals in the artificial soil.
Other low cost materials (such as pumice stone) having similar behaviour (water retention) have also been considered and suggested when available: for example, in the particular case of Canary Island pumice-volcanic stone was preferred to crystal grains.

3.1.6 Economics of the system
A major goal of the project was to assess not only the technical and energetic aspects, but also the economics of the system.
Therefore, after selecting the main technical options, the costs of the products (biomass, electricity and water) were evaluated. These costs depend also on the decision taken about the number of crop cycles.
The amount of the required investment can be divided into biomass power generator, desalination unit and irrigation system. On a 10 ha basis, these costs are, respectively, 1,470,000 ECU (biomass generator), 376,000 ECU (RO desalination unit) and 62,000 ECU (irrigation system) respectively. The total investment cost necessary to install the proposed scheme on a 10 ha area is therefore 1,908,000 ECU.

The costs for electricity production have been evaluated for both the combustion as well as the gasification system, depending on one or two crop cycles. For the combustion unit, these costs are 0.784 (one crop cyle) and 0.444 ECU/kWh$_{el}$ (two crop cycles), while for the gasification unit the electricity production costs are 0.519 and 0.376 ECU/kWh$_{el}$ respectively. However, for the above mentioned reasons, combustion was preferred to gasification in the proposed scheme. The sensitivity of electricity generation costs depending on the fuel cost has also been assessed for the combustion unit. From these calculation, it was clear that the elctricity generation costs are mainly depending on the unit utilisation time, but not that much from little variations in fuel costs. Accordingly, it is essential to make use of two production cycles whenever this is possible.

With regard to the RO seawater desalination, assuming 42,000 TDS sea water, the maximum contribution to the costs is related to energy costs. Therefore, considering one crop cycle, costs of approximately 5.73 ECU/m^3 desalinated water will result by calculating with energy costs of approximately 0.78 ECU/kWh and 100 ECU/t of dry biomass fuel, respectively. When two production cycles are calculated, the specific production costs are reduced to approximately 3.15 ECU/m^3 desalinated water. The fixed costs are distributed to a doubled production, however, the variable costs overrule the fixed costs significantly despite the fact that the electricity costs are reduced to approximately 0.44 ECU/kWh.
For the ED brackish water desalination a comparable calculation was performed as for the salt water desalination. The energy consumption, however, is more dependent on the salt content of the feed water: a feedwater TDS of 3,700 ppm, and of < 600 ppm for the product water was considered. Again, the maximum contribution to the costs is related to energy costs. Production costs of approximately 3.95 ECU/m^3 desalinated water will result by calculating with energy costs of approximately 0.78 ECU/kWh and 100 ECU/t of dry biomass fuel, respectively. When two production cycles are calculated, the specific production costs are reduced to approximately 2.26 ECU/m3 desalinated water. The fixed costs are distributed to a doubled production, however, the variable costs overrule the fixed costs significantly, despite the fact that the electricity costs are reduced to approximately 0.44 ECU/kWh.
Despite of the lower production costs for desalinated water on the basis of brackish water, the "worse case" of desalinated water production on the basis of sea water was taken for the present

project.

Finally, total annual irrigation costs for drip irrigation have been evaluated: the main cost factor for the irrigation system is the irrigation water demand and the costs for irrigation water, which mainly depend on the electricity generation costs. The total production costs result in 298,250 ECU; assuming the already mentioned total biomass production of 28 t/ha (sweet sorghum), the production costs for each tonne of biomass product on the considered area of 10 ha are approximately 1,065 ECU.
If two production cycles are envisaged, the fixed costs remain at the annual costs of 5,810 ECU. The energy and water demands are doubled, but, due to the decrease in specific costs for electricity and water, the increase in the depending costs is less. The annual costs then are 325,710 ECU, giving biomass provision costs of approximately 581 ECU/ton.

As a result of the above reported data, the economic assessment of the entire system was performed.
Based on 100 ECU/t for the biomass fuel for the electricity generation unit in the start-up year, the resulting energy generation costs are 0.784 ECU/kWh, the resulting desalinated water costs are 5.73 ECU/m3 and, for a production quantity of 280 dry tons of biomass on a 10 hectares area, the resulting production costs for one ton of biomass are 1,065 ECU. In order to calculate the sustainability of the entire system in an isolated area situation, two calculation modes have been performed, using different data for the product net profit and the biofuel costs, respectively:

1. Biofuel costs for the start-up year are 100 ECU/t.
2. Following the start-up year the biofuel costs are set equal to the biomass production costs. The selling price for the surplus biomass (40 tons per production cycle) is assumed to be 100 ECU/ton.
3. Following to the start-up year the biofuel costs are set equal to the biomass production costs. The selling price for the surplus of biomass is assumed to be equal to the prodction costs.
4. The depreciation period for the technical equipment is 15 years; the irrigation drip tubes are assumed to be replaced every 10 years, hence requiring for continued depreciation.

The maximum biomass production costs approach 3,136 ECU/t, and come down to 1,635 ECU/t according to a depreciation time of 15 years, when the product selling price every year is set equal to 100 ECU/t and the biofuel price equal to the biomass production costs. The biomass production costs reach a maximum of 2,114 ECU/t, and come down to 1,108 after depreciation, when the product selling price and the biofuel price is set equal to the annual biomass production costs. The entire system is sustainable, but with high costs.
The situation changes significantly, when two production cycles are considered. Based again on 100 ECU/t for the biomass fuel for the electricity generation unit in the start-up year, the resulting energy generation costs are 0.444 ECU/kWh, the resulting desalinated water costs are 3.15 ECU/m^3 and, for a production quantity of 560 dry tons of biomass on a 10 hectares area, the resulting production costs for one ton of biomass are 581 ECU. For this different case also two calculation modes have been performed, using different data for the product net profit and the biofuel costs, respectively.
The maximum biomass production costs approach 1,461 ECU/t, and come down to 770 ECU/t according to a depreciation period of 15 years, when the product selling price every year is set equal to 100 ECU/t and the biofuel price equal to the biomass production costs. The biomass production costs reach a maximum of 1,021 ECU/t, droping to 553 ECU/t after depreciation, when the product selling price and the biofuel price is set equal to the annual biomass production costs. The entire system is much more sustainable, but still with high costs.

In order to allow a better comparison of the cost situation of the system based on biomass as a fuel, these costs were also calculated for an electricity generation system based on diesel fuel. This system is the most conventional system for electricity generation in the small and medium size and rural or isolated sites. The biomass production costs for the diesel solution were therefore calculated: the cost was found to be equal to approx. 500 - 450 ECU/t (before and after depreciation) in the case of “one crop cycle” , while approx. 320 - 250 ECU/t in the case of “two crop cycles”. However, in both cases it is essential to remark that even the use of a standard solution such as a diesel generator would result in a biomass production cost far over 100 ECU/t.

A figure describing the proposed complete bioenergy scheme is reported here below.

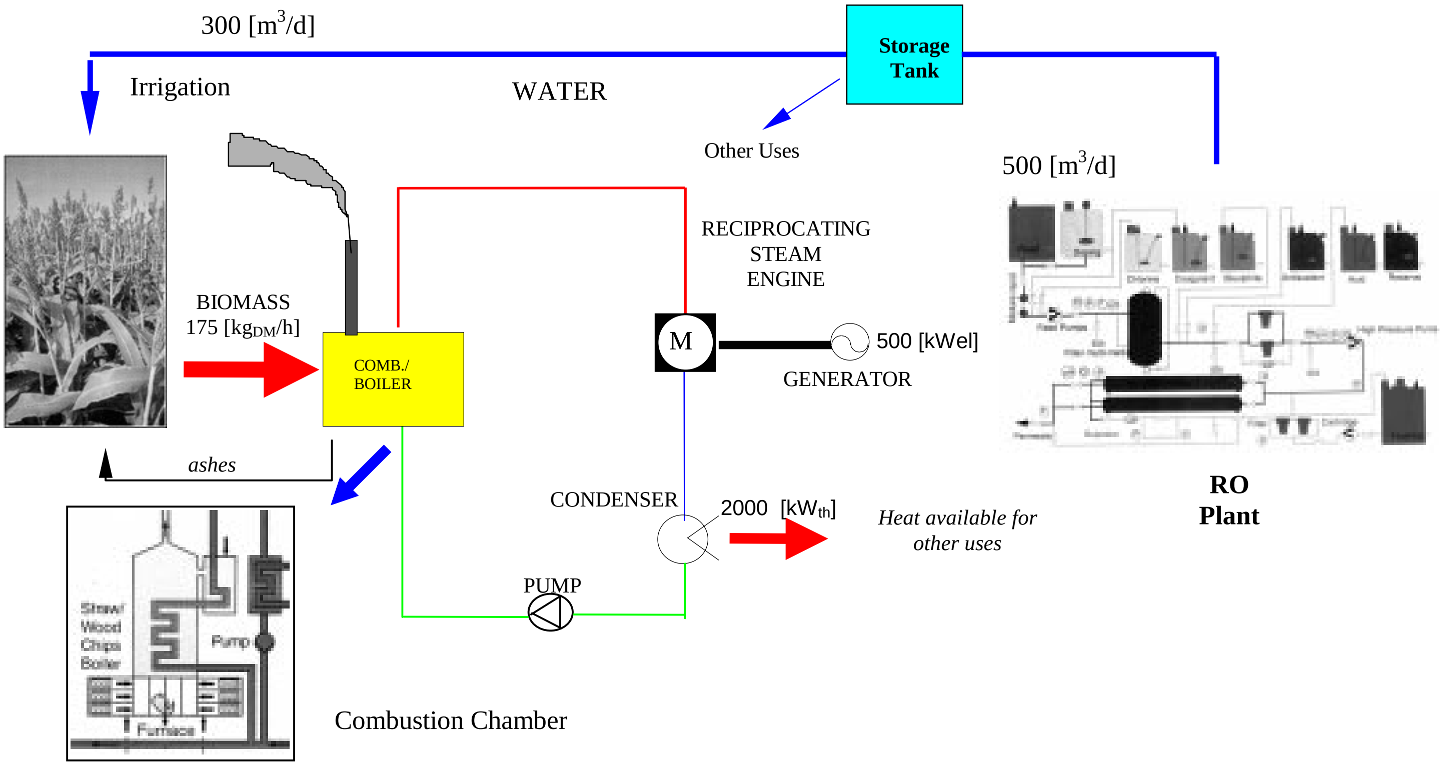

Fig. 3.1: Complete scheme

The possibility offered by the DESERESCUE scheme for land rescuing (which represents the main goal of the project) is reported in the following figure, where a 10 [ha] cultivated area is considered during the first year. The power plant starts to operate at 200 [kW$_e$] power level. Full power will be reached after 8 years: the cultivated area will be increased to approx. 35 [ha]. The installed power is required for 150 [day/y], the duration the Sweet Sorghum crop cycle. The same consideration can be extended to the desalination plants (in this situation, two 500 [m^3/d] capacity plants are necessary: the desalinated water production rises from 300 [m^3/day] the first year to 1000 [m^3/y] after 8 years).

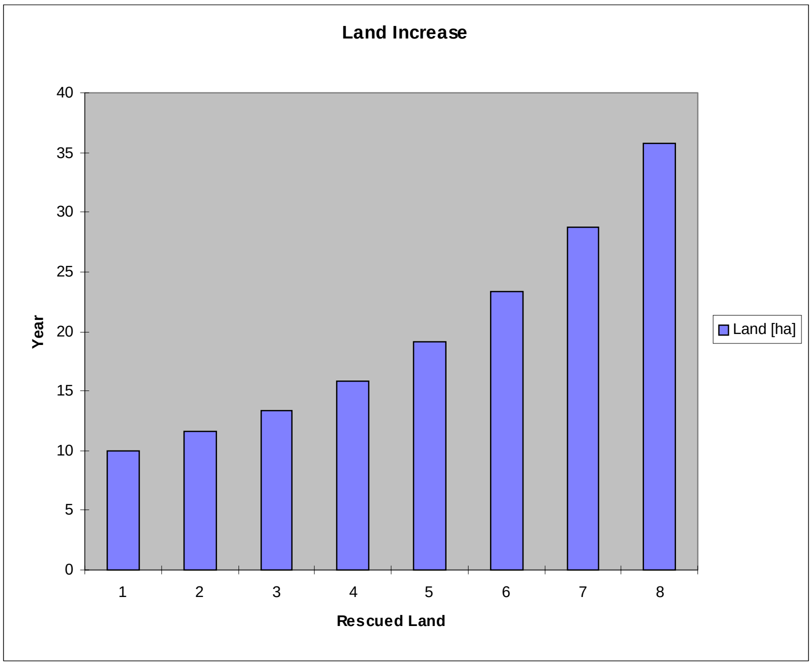

Fig. 3.2: Rescued land per year

A further scale-up of this project was also estimated, referring to a cultivated area of 210 [ha] for the first year. The installed power is provided by three reciprocating steam engines of 1 [MW_e] each. These engines are similar to the model that has been previous presented. Two groups of three cylinders are coupled to the same alternator and moved by the steam produced in the boiler. Calculations have been performed for the first two year of cultivation.

The average gain of rescued land is for the 10 [ha] cultivated area, about 20% per year. For the 210 [ha] area, thanks to the higher efficiency of the desalination plant, the estimated yearly rescued land increase could rise up to 35% per year.

Table 3.5: Estimation of the 210 [ha] system (year 1 - year 2)

	Year 1		Year 2	
Cultivated Area [ha]	**210**		**281**	
Total biomass production [tDM/ha/y]	***28***		***28***	
Grain production [tDM/ha/y]	***3***		***3***	
Bagasse production [tDM/ha/y]	***25***		***25***	
Total Biomass Production for cycle [tDM/y]	***5880***		***7872,43***	
Crop Cycle [d/cycle]	150		150	
Irrigation days [d/cycle]	150		150	
Total Irrigation days [d/y]	150		150	
Biomass Water demand per kgDM	0,185		0,185	
Biomass Water demand per ha [m3/ha/y]	5180		5180	
Total Biomass Water demand [m3/y]	1087800		1456399,7	
50 % Rain [m3/ha/y]	700		700	
Total water contribution from Rain [m3/y]	147000		196811	
Total water demand [m3/y]	***940800***		***1259589***	
Daily water demand [m3/d]	***6272***		***8397***	
CHP Biomass Plant				
Total Electrical Power [kWe]	**2500**		**2500**	
Power self-consumption [kWe]	150		150	
Available Electric Power [kWe]	**2350**		**2350**	
Available Thermal Power [kWth]	10000		10000	
Biomass LHV [kCal/kg] - 20 % Moisture Content	4100		4100	
Electric Efficiency hel [%]	25%		25%	
Combustion Efficiency hcomb [%]	93%		93%	
Electr. Generator Efficiency hgen [%]	95%		95%	
Specific Fuel Consumption SFC [kgDM/kWhe]	0,84		0,84	
Hourly Fuel Energy at Inlet [kWh]	14148		14148	
Hourly Biomass Consumption [kgDM/h]	2098		2098	
Yearly Biomass Consumption [t/y]	4136		5537	
Surplus of Biomass [t/y]	1744		2335	
Desalination unit				
Total installed power	2290		2290	
Specific energy consumption [kWh/m3]	4,8		4,8	
Irrigation unit				
Total installed power [kW]	84,0		84,0	
Specific energy consumption [kWh/m3]	0,125		0,125	
Total Specific Energy Consumpt. per m3 [kWh/m3]	**4,925**		**4,925**	
Total Energy Production [kWh/y]	7008140		9382839	
Total energy required for desalination [kWh/y]	4515840		6046027	
Total energy required for irrigation [kWh/y]	117600		157449	
Total Energy demand [kWh/y]	4633440		6203475	
Total energy required for CHP auxiliares [kWh/y]	1051221		1407426	
Energy Demand per Unit Land [kWh/ha/y]	22064		22064	
Net Energy Balance [kWh]	2374700		3179364	
Net Energy Surplus avail. [kWh/y]	**2374700**	33,9%	**3179364**	33,9%
Net Water Surplus avail. [m3/y]	**482172**	33,9%	**645556**	33,9%
Daily Electric Energy demand [kWhel/d]	30890		41357	
Daily Electric Energy demand for desal.[kWhel/d]	30106		40307	
Daily Electric Energy demand for irrig.[kWhel/d]	784		1050	
Daily Working Time [h/d]	**13,14**		**17,60**	
Total Working Time per Cycle [h/Cycle]	1972		2640	
Total Annual Working Time [h/y]	1972		2640	

3.2 OTHER ASPECTS TO BE CONSIDERED FOR FURTHER IMPROVEMENT

The proposed scheme has always been evaluated assuming the worse conditions: having this type of approach as guideline, it is clear that some possible ways for further improving the system are still present. These aspects are summarised here below.

3.2.1 Biomass selection

With regard to Sweet Sorghum, only bagasse has been considered for estimating the economic balance of the proposed scheme. However, some possible other products could be considered, such as juice or grains. Integrated schemes aimed to obtain simultaneous production of power, heat and bioethanol and based on the proposed combustion technology are today under consideration on the international scene. Moreover, depending on the area under study, grain selling could offer another source of income, particularly in the developing countries.

In addition, the lack of experimentations within EU on salt resistant crops, particularly for *Salicornia bigelovii*, do not allow to consider these crops as a reliable means for implementing the DESERESCUE scheme. However, in other parts of the world (Saudi Arabia, Mexico) long term (6 years) trials have already been successfully performed. Results are extremely interesting and encouraging. The use of this kind of plants would certainly require a particular skill in cultivation and agronomic practices, particularly in protecting the soil from salt accumulation. Moreover, difficulties are expected in the use of this type of biomass in power generators due to their high salt content.

Further research is therefore necessary, both on the cultivation/agronomic as well as technological sides: however, the potential offered by this crop (Salicornia) is really enormous, especially in those remote, arid, and under erosion areas we are dealing with. The energy balance would be so much improved that it is extremely difficult to estimate the impact of these systems. It is important to remark that some advanced methods for crop cultivation in arid areas have already been preliminarly realised (such as the Desert Plant System): these method could be perfectly used for salt resistant crop cultivation.

3.2.2 Power generator

As far as concern the biomass plant the project didn’t consider the heat available from the CHP for additional water production. This heat could play a significant role in the overall energy balance of the complete system. In fact, the chosen CHP plant produces 1200 kW_{th} (at 400 kW_{el} power production level) or 2000 kW_{th} (at 500 kW_{el}). In the present work, this heat has not been considered useful for water production, being its exploitation rather costly if compared to the amount of water that could be produced. However, a deeper analysis on heat use could probably give a positive result through the investigation of naval and/or other industrial technologies. Moreover, the heat available could also be used for increasing the temperature of the feed water at the inlet of the desalination unit. This action could rise the amount of water produced by the RO plant (approx. 3 % if the sea water inlet temperature is increased from 20 °C to 25 °C), maintaining the salt content of the product at acceptable levels (in particular considering that the great part of the desalinated water will mainly be used for irrigation).

From the economic point of view it is reasonable to expect an important reduction in the cost of the biomass generator, thanks to the projects that are currently being designed on the basis of this turn-key plant. It is therefore likely to estimate in a relatively short time a reduction of the cost of the generator to approx. 1,500 $/$kW_{el}$ installed, thanks to serie production, reducing the overall investment and greatly improving the economics of the proposed systems.

Finally, it is essential to remark that the calculations were performed on the basis of the use of the biomass produced as the only fuel for the generator. However, the use of a combustion system instead of gasification will guarantee a great flexibility with respect to fuel the type, offering the chance of adding many other kind of low cost residues as fuel for the generator. In fact, this residues are often available also in remote or isolated areas: as an example, in Tenerife a huge amount of pellets for the transportation of agricultural products exist and is available for power production. It will certainly give very positive low cost contribution to improve the economics of the proposed scheme.

3.2.3 Desalination system

With regard to the desalination system, having as reference the case of seawater desalination, the continuous innovation in membrane technology and desalination technology could produce some positive effects in the short/medium-term period. In fact, the energy consumption per cubic meter of product is continuously decreasing year by year: therefore, it is reasonable to expect a further reduction of this parameter, increasing the overall energy and economic balance of the DESERESCUE scheme.

Finally, if brackish water is available on the site, the energy balance of the system will be dramatically improved (from ≈ 5 kWh_{el}/m^3 to ≈ 3 kWh_{el}/m^3): the amount of water available can be approx. 2 times the value for in case fo sea water desalination. It will offer possibilities of other incomes, such as those from selling drinking water, from the cultivation of other high added values plants (as tomatoes), etc.

3.2.4 Other aspects

Some other aspects could also be coupled with the proposed scheme for a further improvement of the feasibility of the system, in particular from the economic point of view.

For example, the use of Wind Power, a Renewable Energy Source often available in the coastal areas considered in the present work, could be very well added to the proposed scheme, in order to design an more effective hybrid scheme.

Other aspects that could play a very important role, but that have not been considered in the DESERESCUE project, are related to the local economical conditions of the area under study. For example, it has been proven that, even considering all the above mentioned precautionary assumptions, a real possibility exist for rescuing arid land year by year. However, the value of this land has never been taken into account in our economic calculations: this parameter could be extremely relevant, particularly in those areas where turism is present. It could be reasonable to implement some high value turist-related activities in part of these territories.

In addition some spin-off effects with respect to regional development, employment, public finances, the environment and sustainable development should be considered. In fact, the project is suited to generate several contributions within the region:

Contribution to the regional development:

- Some regional activity will be created over the project's lifetime resulting in an overall regional added value.
- A net income value will be created in the region resulting from the work distributed in the region directly or indirectly.
- A regional profit will result from the value of wealth created or maintained in the region
- The possible replicability of the project makes a positive impact on regional development, when the accumulated know-how in the region is assessed

Contribution to job creation:

- Regional companies can carry out work for the investment and operation of the project
- In the course of the job creation a distinct amount will be contributed to social costs. A person, who would perhaps otherwise be unemployed, has a job thanks to the renewable energy project. This results in a lower cost for the public authorities than would have been the case had unemployment benefits to be paid to the person in question, not to mention the

human affects associated with unemployment.

Contribution to environmental protection

- impact of the project on the eco-system, in comparison with what would have arisen by maintaining the situation in the status "as is"
- impact of the project on the landscape and for the visual comfort of local populations, in comparison with what would have arisen by maintaining the situation in the status "as is"

Contribution to sustainable development

- Stimulation of least developed regions as the purpose of the project to makeuse of renewable energies is able to constitute a source of economic development to these regions
- The project aims to contribute towards maintaining a development continuum
- Actions in renewable energy projects promote re-insertion and will complement actions against social exclusion.

4. EXPLOITATION PLANS AND ANTICIPATED BENEFITS

The real market potential of the DESERESCUE is given by the wide area of the world under risk of desertification (see §1).

Another important aspect opening market opportunities to the DESERESCUE project is certainly related to the very positive effects of the proposed system on regional development. In fact, an additional important benefit of the implementation of this bioenergy scheme regards new job creation and social development. A considerable effort to adopt advanced and very efficient biomass cultivation techniques has to be performed, and therefore less developed regions will receive a sensible impulse to improve their agriculture systems, e.g by importing efficient irrigation techniques. A reasonable estimation on new job creation is that 3-4 person will be needed to manage a 10 ha area (biomass cultivation, harvesting, etc.) and operate both the power production and desalination units.

The exploitation of the full (complete) system as it is here presented is today difficult due to the present economical balance: in fact, a major constraints of the proposed scheme is the high cost for the biomass generator (an important cost reduction is already foreseen in short-term time). However, the most important and/or innovative results of the project can be separately exploited.

On the basis of the above mentioned considerations, the research group intend to exploit the results of the study in different ways.

- A small scale (500 kW_{el}) very innovative bioenergy project (not including desalination) based on the technological outcome of the present study can be elaborated to provide Combined Heat and Power to local communities (the present very low efficiency of the existing systems represents a considerable barrier against a wide diffusion of bioenergy, also in those sites where biomass is easely available: in fact, at small scale level, biomass systems are mainly used for heat production only). contacts have already been established.
- The study clearly showed that good market possibilities exist for very small biomass power generators (approx. 100-150 kW_{el}). In fact, no reliable systems are today commercially available at this power level. Therefore, a project aimed to identify and integrate existing technologies to design a completely new generator could be extremely important. This activity would also be in good agreement with the current EU policy of promoting decentralised energy production at small scale level, and with the strategy of the group, constituted by research institutions and companies involved in innovative technologies. Some of the partners have already started to establish contacts at local, regional and EU level to identify an appropriate consortium for this project.
- An integrated system based on Sweet Sorghum can be elaborated on the basis of the technologies identified during the project implementation. It will be able to produce heat, power,

ethanol and some amount of biomass useful for animal feed. Co-operation with developing countries (the most important market for these applications) has already been established.

- Salt resistant crops needs more investigation as it was done in other part of the world (Mexico, USA, Saudi Arabia). A very promising crop was identified, having already showed high production of solid biomass and oil. A project aimed to verify the best crop management under EU conditions could be performed. In order to reduce the environmental risks of the experimentation and to investigate a very promising new method for crop cultivation, a very innovative system (Desert Plant System) could be used during this project.

5. FINAL REMARKS

The approach proposed by the DESERESCUE project is certainly a dynamic and not a static scheme: in other words, the continuous technological evolution which is currently present in the Renewable Energies sector and, in particular, in the Biomass sector, produces dramatic changes in the technical and economical figures assessed during the present study. Some of these innovations, as mentioned in the previous chapters, can already be seen as feasible in the short/medium-terms.

Therefore, one of the major objectives of the project was to present a methodological scheme to be followed in the implementation of these type of studies aimed to rescue arid land through a full bioenergy scheme, and not simply to define a single feasible scheme. On the contrary, the proposed scheme freeze the situation of today technologies, but could soon be overcome by other advanced and/or cheaper systems more economical solutions as innovation takes more and more place in the RE sector.

As a conclusion, DESERESCUE must be regarded as a new approach and method aimed to design possible solutions towards sustainability and land protection, having the “continuous improvement” philosophy as the fundamental key element of its structure.