RURAL SUSTAINABLE DEVELOPMENT THROUGH INTEGRATION OF RENEWABLE ENERGY TECHNOLOGIES IN POOR EUROPEAN REGIONS

**Specific Targeted Research Project** (Project no. INCO – CT – 2004 - 509204)

# WORK PACKAGE 3: Model Development and application for determining optimum IRES schemes in the selected regions

## DELIVERABLE 7:

## Schemes with optimal IRES for the target regions

### § Presentation of Schemes resulted from DOIRES runs

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## DOIRES SOFTWARE - IRES SCHEMES PRESENTATION

Selected IRES schemes stem from the combination of two processes: optimization process where specific scenarios are optimised and multi-criteria analysis where alternative optimised scenarios are outranked according to selected sustainability criteria. Software facility makes available exploration of the feasible alternatives through changes in preferences and scenarios.

The background of multi-criteria analysis has been presented in detail in Deliverable 6 (DOIRES presentation). The user can run more that one multi-criteria analyses for the same combination of scenarios by weighting differently the criteria.
Different weighting can result in different ranking of scenarios.

This document is only part of D7, IRES schemes, and it pertains with the description of the runs in DOIRES software. D7 is completed by the doires files (all input data and results incorporated in DOIRES environment), results files in excel and multi-criteria analyses files.

### ***A. Partner No 1, AUA, Milos case study***

For Milos case study three scenarios of IRES were compared in multi-criteria analysis.

A1. Optimisation process

The optimization process has been implemented for 3 time periods each one corresponding to 5 years of energy planning and 4 time intervals for the formation of Load Duration Curves.

A1.1 Scenario definition

i) Scenario 1

- Centralised electricity production is used, giving electricity to the grid, for the production of which, technologies selected are fossil fuel electricity generators, wind turbines, hydro power and waste-to-energy (RDF technology) to satisfy electricity demands of domestic, industrial, agriculture and solid waste management energy sectors.
- Industry sector though, does not satisfy its electric power demands only by the grid, but a distributed energy production is also used, with fossil fuel generators again and also wind turbines are chosen to make an optimum combination. (a substitution of fossil fuel generators may be foreseen).
- Electricity needs for desalination will be satisfied in this scenario by combination of wind turbines and photovoltaics.
- Biomass and biogas generators are used for distributed production for waste water treatment and biogas plant energy sector. A part though of the load of waste water treatment sector will be satisfied by a stand alone installation of photovoltaics.

- District heating is used for domestic and agriculture energy sectors with technologies to be compared for its production, geothermal and biomass burners
- Space heating of domestic sector is also satisfied by fossil fuel boilers Fossil fuel boilers have a separate load duration curve but by setting the same load number both loads are incorporated in the same equality and inequality constraint in order that fossil fuel boilers could be substituted by district heating.
- The same is valid for agriculture sector. Fossil fuel boilers could be substituted by district heating.
- A separate load of heat demand for agriculture (for drying) is satisfied with heat pumps use.
- Process heating demands of industry will be satisfied by fossil fuel boilers and also heat output of CHP gas turbines.
- For sanitary water needs of domestic sector solar collectors are used.
- Heat demands for desalination will be satisfied by two technologies to be compared: geothermal heating and solar collectors.
- For waste water treatment and biogas plant sectors the heat demands will be covered by solid waste burning and geothermal heat pumps.
- Gas turbines CHP give electricity to the grid) and thermal energy to specific industry load, partially satisfied by fossil fuel boilers.
- Primary energy source production is foreseen with vegetable oil production from sunflower crop and participation in increasing, throughout the time horizon, shares in diesel engines trucks.

ii) Scenario 2

The same description of scenario was followed for scenario 2

A1.2 Constraints taken into account

The scenario follows the general constraints for specific technologies selected to be configured like availability of technologies, energy generation and consumption balancing according to the specific loads, Peak demand satisfaction, Plant facility operation limits, Limits on energy generation etc as described in D6.

Significantly, the following constraints were imposed on the 1$^{st}$ scenario optimisation process:

- Primary energy consumption: Upper bound of crude oil fuel consumption was set to 10,000 tones (greater than the present fuel consumption) and upper bound of rdf was set to 8000 tones.
- Share of one technology to satisfaction of specific load level: Specific technology’s of wind turbines power output was set to be up to no limit percentage of total power output from the sum of technologies that participate in the load satisfaction, to which the particular technology corresponds.
- Share of Renewable Energy produced in the system: A minimum RES share in the total power output in the system was set to 20%.
- Limits on renewable energy potentials: The RES potential for hydro was given up to 20000 MWh and for solid to waste (rdf) up to 80000 MWh.

- Emission limits: The total annual emission of the *r*-th pollutant was given with an upper bound loose.

On the 2nd scenario optimization process the above constraints were differentiated according to:

- Primary energy consumption: Upper bound of crude oil fuel consumption was set to 7,000 tones (stricter than in scenario 1).
- Share of one technology to satisfaction of specific load level: Specific technology's of wind turbines power output was set to be up to 30% of total power output from the sum of technologies that participate in the load satisfaction, to which the particular technology corresponds.
- Share of Renewable Energy produced in the system: A minimum RES share in the total power output in the system was set to 30%.
- Limits on renewable energy potentials: The RES potential of hydro was given greater (50,000 MWh).
- Emission limits: The total annual emission of the *r*-th pollutant was given with an upper bound stricter than 1st scenario .

On the 3rd scenario optimization process the above constraints were differentiated according to:

- Primary energy consumption: Upper bound of rdf fuel consumption was set to 10,000 tones (looser than in scenario 1 and 2).
- Share of one technology to satisfaction of specific load level: Specific technology's of wind turbines power output was set to be up to 30% of total power output from the sum of technologies that participate in the load satisfaction, to which the particular technology corresponds.
- Share of Renewable Energy produced in the system: A minimum RES share in the total power output in the system was set to 30%.
- Limits on renewable energy potentials: The RES potential of hydro was given intermediate of the above 2 scenarios (30,000 MWh).
- Emission limits: The total annual emission of the *r*-th pollutant was given with an upper bound stricter than 1st scenario .

## A1.3 Optimised configurations – Outputs of the model

Running DOIRES for the above described scenarios gave the following optimised configurations of technologies for which the additional power to be installed in the three time periods is given in Table 1.3.

The model chose to install additional power for biomass electricity generators (1.15 MW) for distributed electricity generation, wind turbines (their capacity vary between scenarios) for centralized electricity generation, PV for desalination needs (1.15 MW) and PV for waste water treatment needs (1.15 MW). For heating, geothermal heating system for space heating-cooling of 6.57 MW and also a thermal desalination unit of

2.3 MW. Solar collectors' capacity for sanitary water of domestic sector will increase by 2.75 MW and HP for agriculture is suggested to be in use for another 1.15 MW.

The model has selected between possible combinations of specific technologies for satisfaction of specific loads, like biomass generators against biogas generators, or geothermal district heating against biomass source.

Some selected technologies competed over others. Not selected technologies to be installed were hydro and solid waste to energy for centralised electricity generation. Biogas over biomass generators for distributed electricity generation. For desalination PV was selected over wind turbines. No biomass heating was selected for district heating, only geothermal energy. Last, geothermal energy also competed solar collectors for thermal desalination unit.

All installations is suggested to be in the 1st time period

In scenario 2, where additional constraint is imposed for participation of fossil fuel generators up to 10%, new technologies are chosen to participate, like waste-to-energy and CHP technology. Power output of fossil fuel generators is confined.

Table A1.3.1 Additional power to be installed in MW

| | Additional Power to be installed in MW | | |
|---|---|---|---|
| | Scenario 1 | Scenario 2 | Scenario 3 |
| centr_Tech1_1 | 0 | 0 | 0 |
| distr_Tech1_4_2 | 0 | 0 | 0 |
| distr_Tech2_2_7 | 1.15 | 1.15 | 1.15 |
| distr_Tech2_2_8 | 1.15 | 1.15 | 1.15 |
| distr_Tech3_2_7 | 0 | 0 | 0 |
| distr_Tech3_2_8 | 0 | 0 | 0 |
| centr_Tech4_1 | 12.58 | 4.70 | 12.49 |
| distr_Tech4_5_5 | 0.29 | 0.29 | 0.29 |
| distr_Tech4_4_2 | 2.50 | 2.44 | 2.93 |
| distr_Tech5_6_7 | 1.15 | 1.15 | 1.15 |
| distr_Tech5_5_5 | 0.86 | 0.86 | 0.86 |
| centr_Tech6_1 | 2.86 | 7.14 | 4.29 |
| centr_Tech7_1 | 0.55 | 0 | 1.40 |
| heatdemands_Tech7_2 | 0 | 0 | 0 |
| district_Tech8_1 | 4.6 | 4.6 | 4.6 |
| heatdemands_Tech8_7_5 | 0 | 0 | 0 |
| sanwater_Tech9_6_1 | 1.3 | 1.3 | 1.3 |
| heatdemands_Tech9_7_5 | 2.3 | 2.3 | 2.3 |
| spheating_Tech10_1_1 | 0 | 0 | 0 |
| heatdemands_Tech10_5_2 | 0 | 0 | 0 |
| heatdemands_Tech10_1_3 | 0 | 0 | 0 |
| district_Tech11_1 | 0 | 0 | 0 |
| heatdemands_Tech12_4_3 | 1.15 | 1.15 | 1.15 |
| heatdemands_Tech12_2 | 2.3 | 2.3 | 2.3 |
| diesel_Tech14 | 0 | 0 | 0 |
| otto_Tech15 | 0 | 0 | 0 |
| chp_Tech13 | 0 | 0 | 0 |

Table A1.3.2 Summary of results

| | Scenario 1 | Scenario 2 | Scenario3 |
|---|---|---|---|
| total emissions in kt | 141.92717 | 73.90819 | 214.07624 |
| total cost in Millions Euros | 58.14687 | 46.92056 | 58.8518 |
| Fuel resource indicator in kg/kWh | 0.11894 | 0.08696 | 0.1372 |
| cost of energy production in Euros/kWh | 0.11062 | 0.08926 | 0.11196 |
| Biofuels share in primary energy supply (%) | 45.62215 | 47.15735 | 64.47501 |
| Non imported energy production-security (%) | 68.40164 | 76.04436 | 74.90615 |
| Renewable energy share in energy and electricity (%) | 65.47262 | 73.11534 | 71.97713 |
| Non Carbon energy share in energy and electricity (%) | 74.25969 | 81.90241 | 80.7642 |

Scenario 2 gives an alternative option of smaller cost and more environmentally friendly (less emissions, greater RES share).

A2 Multi-criteria analysis

The following sustainability indicators were used for multi-criteria analysis of Milos case:

fuel resource indicator (kg/kWh)

cost of energy production (€/kWh)

total cost (M€)

Renewable energy share (%)

Non carbon energy share (%)
$CO_2$ emissions
Non imported energy production – security (%)

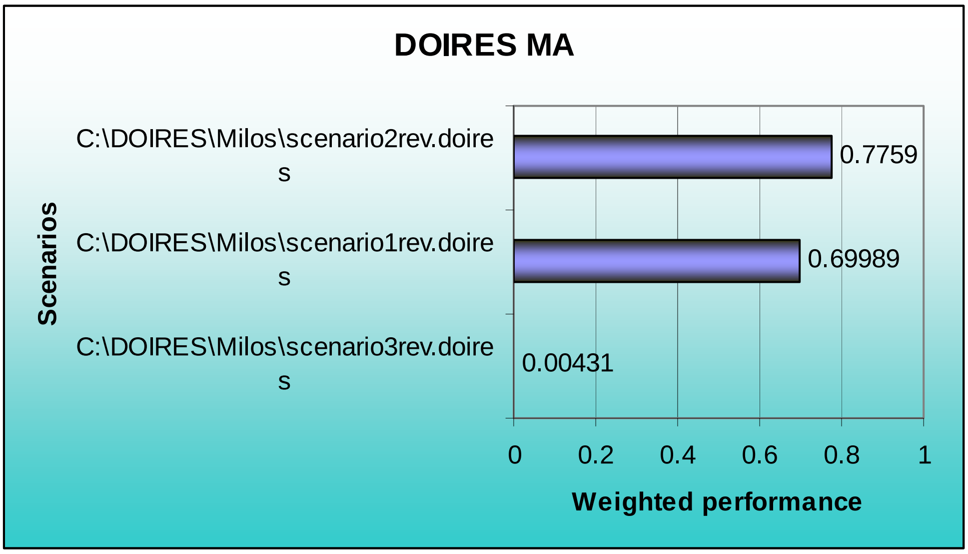
By weighting differently the criteria multi-criteria analysis was run twice and the results were as following:

First it was given weights of 20% to resource dimension indicators, 40% to economic dimension indicators and 40% to environmental dimension indicators with the values below:

| Indicators | weights |
|---|---|

| | |
|---|---|
| fuel resource indicator (kg/kWh) | 0.2 |
| cost of energy production (€/kWh) | 0.15 |
| total cost (M€) | 0.15 |
| Renewable energy share (%) | 0.1 |
| Non carbon energy share (%) | 0.1 |
| CO2 emissions kT | 0.2 |
| Non imported energy production – security (%) | 0.1 |

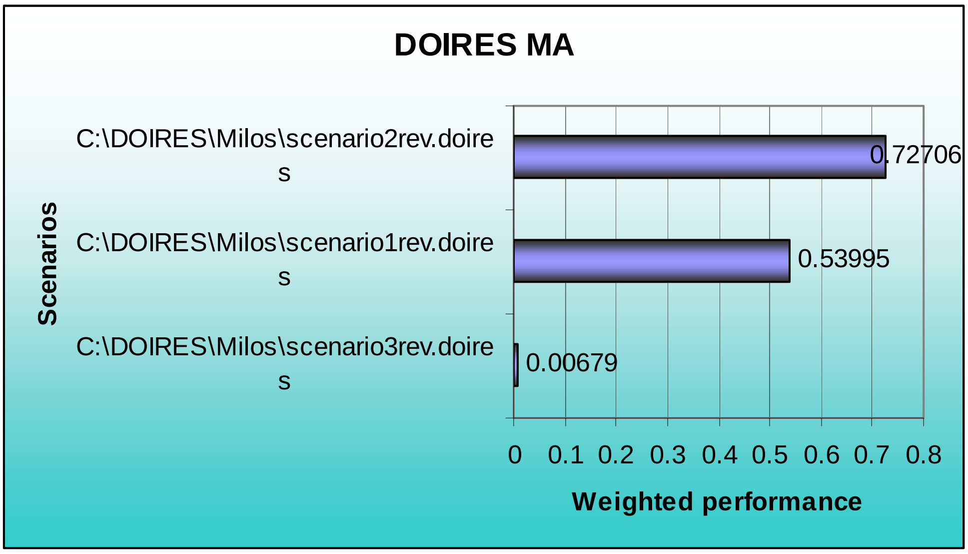
Scenario 2 was outranked with a weighted performance 0.7759 over scenario1 with 0.67 weighted performance:




In second run it was given weights of 20% to resource dimension indicators, 14% to economic dimension indicators and 66% to environmental dimension indicators with the values below:

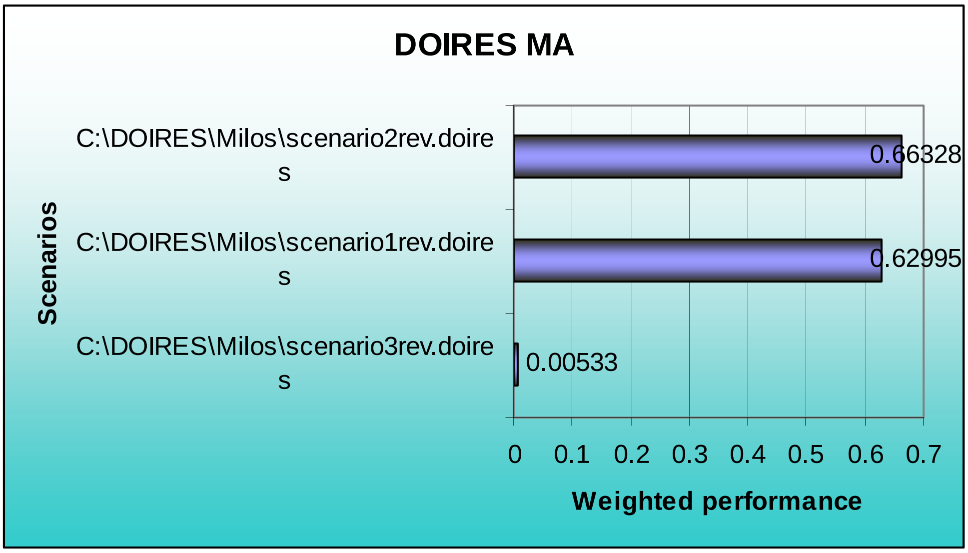
| Indicators | weights |
|---|---|
| fuel resource indicator (kg/kWh) | 0.2 |
| cost of energy production (€/kWh) | 0.02 |
| total cost (M€) | 0.02 |
| Renewable energy share (%) | 0.2 |
| Non carbon energy share (%) | 0.16 |

| | |
|---|---|
| CO2 emissions kT | 0.3 |
| Non imported energy production – security (%) | 0.1 |




Scenario 2 was again outranked with a weighted performance 0.727 over scenario 1 with 0.54 weighted performance:

If we give even greater weight to environmental (76%) than economic dimension (4%) then the weighted performances of the two scenarios tend to coincide:




The results give a fair idea on conflicts among criteria, in this case a strong conflict exists between RES penetration and expenses assumed, that is partially compensated by security of supply and secondly by $CO_2$ emissions reduction. In all cases multi-criteria analysis was in favour of scenario2, which is selected.

## B. Partner No 2, WIP, Achental case study

For Achental case study three scenarios of IRES were compared in multi-criteria analysis.

### B1. Optimisation process

The optimization process has been implemented for 3 time periods each one corresponding to 3 years of energy planning and 4 time intervals for the formation of Load Duration Curves.

#### B1.1 Scenario definition

i) Scenario 1

**Electric power:**

- Centralised electricity production is used, giving electricity to the grid, for the production of which, technologies selected are biogas generators, wind turbines, photovoltaics and hydro power to satisfy electricity demands of domestic, industrial, agriculture, waster water treatment, biogas plant and primary energy source production energy sectors.
- All energy sectors listed above satisfy their electric power demands only by the grid; no distributed energy production is used. Decentralized electricity production can be found in the region, e.g. by PV panels installed on private roof tops or small scale biogas electricity generators. However, all electricity produced on a decentralized base is used indirectly, since it is fed into the grid and thus supply centralized load duration curve.

**Thermal power:**

- Space heating demands of domestic and agriculture sectors are satisfied by biogas generators and biomass heating technologies. In addition space heating demand of domestic sector is supplied by solar heating technology. Accordingly the software creates the following LDCs:
    - spheating_biogas_generators_1
    - spheating_solar_heating_1_1
    - spheating_Biomass_heating_1

- Sanitary water demand of domestic energy sector is supplied by solar heating and biomass heating technologies:
    - sanwater_solar_heating_4_1
    - sanwater_Biomass_heating_4_1

- District heating is used for industrial energy sector with biomass heating technology to be compared for its production:
    - district_Biomass_heating_1_2

- Process heat demands of industrial sector are also supplied by biomass heating technology:
    - heatdemands_Biomass_heating_8_2

- For agriculture sector district heating demand is supplied by biomass heating technologies:

- district_Biomass_heating_7_3

- A separate load of heat demand for waste water treatment sector (heat that is not produced internally) is supplied by biomass heating technology:
    - heatdemands_Biomass_heating_5_5

- Another separate load of heat demand for biogas plant (heat that is not produced internally) is supplied by biogas generators and biomass heating technologies:
    - heatdemands_biogas_generators_6_6
    - heatdemands_biomass_heating_6_6

**Other power:**

- CHP technology is used to supply heat and electricity demands fo waste water treatment plant and biogas plant. The technology to be compared is CHP biogas generator:
    - chp_biogas_generators
    - chpEL_biogas_generators_1
    - chpTH_biogas_generators_5_5
    - chpTH_biogas_generators_1_6

ii) Scenario 2

The same description of scenario was followed for scenario 2

B1.2 Constraints taken into account

The scenario follows the general constraints for specific technologies selected to be configured like availability of technologies, energy generation and consumption balancing according to the specific loads, Peak demand satisfaction, Plant facility operation limits, Limits on energy generation etc. as described in D6.

Significantly, the following constraints were imposed on the 1$^{st}$ scenario optimisation process:

- Primary energy consumption: Upper bound of crude oil fuel consumption was set to 100,000 tones (greater than the present fuel consumption).
- Share of one technology to satisfaction of specific load level: Specific technology's of diesel generators power output was set to be up to no limit percentage of total power output from the sum of technologies that participate in the load satisfaction, to which the particular technology corresponds.
- Share of Renewable Energy produced in the system: A minimum RES share in the total power output in the system was set to 20%.
- Limits on renewable energy potentials: The RES potential was given ample.
- Emission limits: The total annual emission of the *r*-th pollutant was given with an upper bound loose.

On the 2$^{nd}$ scenario optimization process the above constraints were differentiated according to:

- Percentage of technology to lead number and kind of power demand:

- Upper bound of biogas technology share was set to 50% (much stricter than in scenario 1).
- Wind turbines share was set to 30%
- Central PV was set to 30%
- Solar heating for sanitary water was set to 20%
- Biomass heating for space heating was set to 60%

- Limits on renewable energy potentials: The RES potential for solar heating for sanitary water increased from 8.100 MWh/year (1st scenario) to 18.000 MWh/year.

On the 3rd scenario optimization process the above constraints were differentiated according to:

- Percentage of technology to lead number and kind of power demand:
  - Wind turbines share was set to 10%
  - Central PV was set to 10%

B1.3 Optimised configurations – Outputs of the model

Running DOIRES for the above described scenario gave the following optimized configuration of technologies for which the additional power to be installed in the three time periods is given in Table 1.3.

The model chose to install additional power for biogas electricity generators (1st year: 17965.805 kW, 2nd year: 21188.39 kW, 3rd year: 24723.05 kW) for central electricity generation, wind turbines (10 kW for all years) for centralized electricity generation, PV (800 kW for all years) and hydropower (9000 kW for all years), the latter two also for centralized electricity generation.

For heating, biogas generators for space heating of 19457.49 kW additional power will be installed in the 1st year, 23752.08 kW in the 2nd year and 28390.5 kW in the 3rd year. Additional power of 400 kW biogas heating systems will be installed in all 3 years.
Solar collectors' capacity for sanitary water of domestic sector will increase by 903 kW for all three years. Heat demands for space heating will also be covered by biomass heating systems of 34255.545 kW for all 3 years, district biomass heating for industry sector of 16500 kW for all 3 years, district biomass heating for agricultural sector of 14486.85 kW in 1st and 2nd year and 20281.59 kW in 3rd year. Sanitary water demand of domestic sector will also be covered through additional power of biomass heating systems of 12550.89 kW in 1st year, 16942.935 kW in 2nd year and 22876.645 in 3rd year. 28390.5 kW additional power of centralized CHP biogas generators will be installed in all 3 years. 400 kW additional capacity of biogas CHP will be installed for waste water treatment.

The model has selected between possible combinations of specific technologies for satisfaction of specific loads, like biomass generators against biogas generators. Some selected technologies competed over others. Not selected technology to be installed was solar heating technology for space heating.

Additional power to be installed are the same for all three scenarios. The actions taken for alternative scenario are not so drastic to have different outputs for additional power to be installed. For this reason in table B1.3.1 only figures of one scenario is presented, since the ones of scenario 2 and scenario 3 are the same.

Table B1.3.1 Additional power to be installed in kW: Scenario 1 - 3

| Technology | Year | Total Capacity (kW) |
|---|---|---|
| centr_biogas_generators_1 | 1 | 17965.805 |
| | 2 | 21188.39 |
| | 3 | 24723.05 |
| centr_wind_turbines_1 | 1 | 10 |
| | 2 | 10 |
| | 3 | 10 |
| centr_Photovoltaics_1 | 1 | 800 |
| | 2 | 800 |
| | 3 | 800 |
| centr_Hydropower_1 | 1 | 9000 |
| | 2 | 9000 |
| | 3 | 9000 |
| spheating_biogas_generators_1 | 1 | 19457.49 |
| | 2 | 23752.08 |
| | 3 | 28390.5 |
| heatdemands_biogas_generators_6_6 | 1 | 400 |
| | 2 | 400 |
| | 3 | 400 |
| sanwater_Solar_heating_4_1 | 1 | 903 |
| | 2 | 903 |
| | 3 | 903 |
| spheating_Solar_heating_1_1 | 1 | 0 |
| | 2 | 0 |
| | 3 | 0 |
| spheating_Biomass_heating_1 | 1 | 34255.545 |
| | 2 | 34255.545 |
| | 3 | 34255.545 |
| district_Biomass_heating_1_2 | 1 | 16500 |
| | 2 | 16500 |
| | 3 | 16500 |
| district_Biomass_heating_7_3 | 1 | 14486.85 |
| | 2 | 14486.85 |
| | 3 | 20281.59 |
| heatdemands_Biomass_heating_5_5 | 1 | 1096.862 |
| | 2 | 1096.862 |
| | 3 | 1152.05 |
| heatdemands_Biomass_heating_6_6 | 1 | 689.85 |
| | 2 | 1241.73 |
| | 3 | 2235.114 |
| sanwater_Biomass_heating_4_1 | 1 | 12550.89 |
| | 2 | 16942.935 |
| | 3 | 22875.645 |

| | | |
|---|---|---|
| heatdemands_Biomass_heating_8_2 | 1 | 4139.1 |
| | 2 | 4139.1 |
| | 3 | 5387.728 |
| chp_biogas_generators | 1 | 28390.5 |
| | 2 | 28390.5 |
| | 3 | 28390.5 |
| chpEL_biogas_generators_1 | 1 | 28390.5 |
| | 2 | 28390.5 |
| | 3 | 28390.5 |
| chpTH_biogas_generators_5_5 | 1 | 400 |
| | 2 | 400 |
| | 3 | 400 |
| chpTH_biogas_generators_1_6 | 1 | 400 |
| | 2 | 400 |
| | 3 | 400 |

Other outputs of the model are given in Table B1.3.2 below

Table B1.3.2 Summary of results

| | **Scenario 1** | **Scenario 2** | **Scenario 3** |
|---|---|---|---|
| total emissions in kt | 20.039.194 | 20.039.194 | 20.039.194 |
| total cost in Millions Euros | 114.35297 | 114.35297 | 114.35297 |
| total produced energy in GWh | 2.71 | 2.71632 | 2.71632 |
| total produced res energy in GWh | 1109.41883 | 1109.41883 | 1109.41883 |
| Fuel resource indicator in kg/kWh | 0.34151 | 0.34151 | 0.34151 |
| cost of energy production in Euros/kWh | 0.10307 | 0.10307 | 0.10307 |
| Non imported energy production-security (%) | 90.22063 | 90.22063 | 90.22063 |
| Renewable energy share in energy and electricity (%) | 100 | 100 | 100 |
| Non Carbon energy share in energy and electricity | 100 | 100 | 100 |
| Biofuels share in primary energy supply (%) | 100 | 100 | 100 |

## B2 Multi-criteria analysis

The following sustainability indicators were used for multi-criteria analysis of Achental case:

fuel resource indicator (kg/kWh)

new job indicator (number of jobs)

cost of energy production (€/kWh)

total costs (M€)

Non carbon energy share (%)

Emissions of GHG (kTCO2 eq)

By weighting differently the criteria we run twice multi-criteria analysis twice and we got the following results:

| Indicators | weights |
|---|---|
| fuel resource indicator (kg/kWh) | 0.2 |
| new job indicator (number of jobs) | 0.2 |
| cost of energy production (€/kWh) | 0.1 |
| total costs (M€) | 0.1 |
| Non carbon energy share (%) | 0.2 |
| Emissions of GHG (kTCO2 eq) | 0.2 |

Weighted performance

| Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|
| **0.62922** | **0.5924** | **0.2** |

| Indicators | weights |
|---|---|
| fuel resource indicator (kg/kWh) | 0.1 |
| new job indicator (number of jobs) | 0.6 |
| cost of energy production (€/kWh) | 0.05 |
| total costs (M€) | 0.05 |
| Non carbon energy share (%) | 0.05 |
| Emissions of GHG (kTCO2 eq) | 0.15 |

Weighted performance

| Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|
| **0.6** | **0.4573** | **0.3607** |

## C. Partner No 3, ETA, Limina case study

For the Limina case study, four scenarios of IRES were compared in multi-criteria analysis.

### C1. Optimisation process

The optimization process has been implemented for a period of 20 years. Only one time interval for the duration of the Load Duration Curve was used due to only annual data being available for the region. The sectors are domestic, agriculture, industry and tertiary. Tertiary here means a combination of the commercial and municipal sectors. The idea in using the software was to increase the share of renewable energy into the system over the 20 year planning period.

#### C1.1 Scenario definition

i) Scenario 1

- PV, Wind Turbines and biomass-electricity are used to produce centralised electricity production to satisfy electricity demands of all sectors: domestic, agriculture, industry, tertiary. Wind energy is expected to be online in year 3, as it is a project already being planned, but no additional capacity is foreseen.
- There is no "native" power generation in Limina, all electricity demand is imported.
- PV is also used in a distributed fashion, also across all sectors.
- Space heating in the domestic is served with diesel, LPG, fuel oil and natural gas boilers. This is the same in the tertiary sector, save the fuel oil, which is not used. In addition to these already installed technologies, biomass-heating systems are specified to try to replace these fossil fuel systems.
- Sanitary water in the domestic and tertiary sectors is served with diesel, LPG, and natural gas boilers. In addition to these, thermosyphon solar systems are to replace this demand, as well as the capacity from any biomass-heating systems.
- For the industrial and agricultural sector, the heat demands are continued to be served with fossil fuel boilers.
- Primary energy source production is foreseen with agricultural crop residues, from short rotation energy crops (here sweet sorghum), and from animal wastes (manure).

#### C1.2 Constraints taken into account

i) Scenario 1

- In order to force new installations for RE, the purchased electricity is forced to decrease  a scenario was set up requiring that purchased electricity decrease 12% per year, and for the minimal share of RE to be at least 58% by 20 years.

ii) Scenario 2

- This scenario uses Scenario 1 as a base, and decreases the installed capacity of fossil-fuel fired boilers between -3% and -10% per year, in order to further force an increase in biomass-fueled boilers (and solar thermal).

iii) Scenario 3

- This scenario uses Scenario 2 as a base, but assumes a "peak-oil" supply situation, where the prices of fossil fuels increase more drastically, on the order of 10% per year for the full 20 years (a 6.7 fold increase).

iv) Scenario 4

- This scenario uses Scenario 1 as a base, but with emissions-limits imposed, starting at 30 000 tonnes per year, decreasing at -20% per year until stabilized at 6000 tonnes per year.

C1.3 Optimised configurations – Outputs of the model

DOIRES was ran for the above four scenarios, to see how the different technologies would interact in the face of different constraints and future scenarios. The results are presented in Tables 1.3.1 and 1.3.2.

12.75 MW of wind was specified as existing in year 3, as this is currently already under planning. Thus a large part of demand can already be met by RE. DOIRES then suggested the installation of a 4.1 MW biomass-fired electric plant, 1.44 MW of centralized PV, and 6959 kW of decentralized PV, in all cases. For hot water heating, 450 kW (i.e. 644 $m^2$) is suggested, again in all cases. 330 kW of biomass heating systems is suggested in scenario 1 and 2, with 3118 kW suggested in Scenario 3, and 3643 kW in Scenario 4. The model also suggests the installation of LPG boilers in all scenarios: 6559 kW in Scenario 1, 6749 kW in Scen. 4, 5363 kW in Scen. 3, 5546 kW in Scen. 4. Lastly, in Scenario 3, 2094 kW of natural gas boilers is also suggested.

Most of the installations are generally suggested over the period of 20 years, with centralized PV, biomass-electric and the majority of the fossil fuel boilers propositioned in the first year.

What is interesting is that as restrictions are placed on CO2 emissions (Scenario 4), or if the price of fossil-fuels increases greatly, much more biomass-based heating systems are suggested. Clearly, pellets and woodchips are much cheaper in such a scenario. However, the installed costs are higher, as well as cost per kWh.

What changes significantly across scenarios is the percentage of biofuel used (see Table 1.3.2). This is clearly how the model manages to deal with the constraints for renewable energy. While some biofuel can be produced onsite, reaching 81% biofuel in Scenario 4 could not be possible without imports. It is thus not very realistic to base planning on that aspect.

As expected though, a great number of PV installations are made, totalling over 8 MW in installed capacity. This, combined with the wind and biomass-electric installations makes Limina almost completely independent electrically.

However, it is clear that due to the lack of resources, the demands cannot be met with RE alone, and even new fossil-fuel boilers are to be installed to meet the thermal demands. This also puts a limit to how much GHG reductions could be possible.

Table C1.3.1 Additional power to be installed in kW

Additional Power to be installed in kW

| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| centr_Tech2_1 | 4142.7 | 4142.7 | 4142.7 | 4142.7 |
| centr_Tech4_1 | 0 | 0 | 0 | 0 |
| centr_Tech5_1 | 1444.1 | 1444.1 | 1444.1 | 1444.1 |
| distr_Tech5_1_1 | 3505.2 | 3505.2 | 3505.2 | 3505.2 |
| distr_Tech5_1_2 | 439.3 | 439.3 | 439.3 | 439.3 |
| distr_Tech5_1_3 | 518.65 | 518.65 | 518.65 | 518.65 |
| distr_Tech5_1_4 | 2495.5 | 2495.5 | 2495.5 | 2495.5 |
| sanwater_Tech9_2_1 | 326.6 | 326.6 | 326.6 | 326.6 |
| sanwater_Tech9_6_4 | 124.2 | 124.2 | 124.2 | 124.2 |
| spheating_Tech10_1_1 | 0 | 0 | 0 | 0 |
| heatdemands_Tech10_4_2 | 0 | 0 | 0 | 0 |
| heatdemands_Tech10_5_3 | 0 | 0 | 0 | 0 |
| sanwater_Tech10_6_4 | 0 | 0 | 0 | 0 |
| sanwater_Tech10_2_1 | 0 | 0 | 0 | 0 |
| spheating_Tech10_7_4 | 0 | 0 | 0 | 0 |
| spheating_Tech11_1_1 | 330.2 | 330.2 | 2855.4 | 2855.4 |
| heatdemands_Tech11_5_3 | 0 | 0 | 0 | 525.11 |
| sanwater_Tech11_6_4 | 0 | 0 | 0 | 0 |
| sanwater_Tech11_2_1 | 0 | 0 | 0 | 0 |
| spheating_Tech11_7_4 | 0 | 0 | 262.56 | 262.56 |
| spheating_Tech14_1_1 | 2425.9 | 2580.2 | 1776.1 | 1762 |
| heatdemands_Tech14_4_2 | 1372.1 | 1372.1 | 1372.1 | 1372.1 |
| heatdemands_Tech14_5_3 | 1632.5 | 1632.5 | 1632.5 | 1632.5 |
| sanwater_Tech14_6_4 | 11.1 | 11.1 | 11.1 | 11.1 |
| sanwater_Tech14_2_1 | 42.25 | 42.25 | 42.25 | 42.25 |
| spheating_Tech14_7_4 | 1074.9 | 1110.9 | 528.64 | 726.09 |
| spheating_Tech15_1_1 | 0 | 0 | 0 | 0 |
| heatdemands_Tech15_4_2 | 0 | 0 | 0 | 0 |
| heatdemands_Tech15_5_3 | 0 | 0 | 0 | 0 |
| sanwater_Tech19_2_1 | 0 | 0 | 0 | 0 |
| heatdemands_Tech19_4_2 | 0 | 0 | 1149.2 | 0 |
| heatdemands_Tech19_5_3 | 0 | 0 | 0 | 0 |
| sanwater_Tech19_6_4 | 0 | 0 | 0 | 0 |
| spheating_Tech19_1_1 | 0 | 0 | 0 | 0 |
| spheating_Tech19_7_4 | 0 | 0 | 944.43 | 0 |

Other outputs of the model are given in Table C1.3.2 below.

Table C1.3.2 Summary of results

| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| total emissions in kt | 251.31 | 251.33251 | 161.67838 | 149.90688 |
| total cost in Millions Euros | 171.36 | 169.34229 | 203.64308 | 181.31271 |
| total produced energy in GWh | 1957 | 1957.31688 | 1957.31688 | 1957.31688 |
| total produced res energy in GWh | 1038 | 1037.96304 | 1351.28791 | 1406.53814 |
| Fuel resource indicator in kg/kWh | 0.10323 | 0.10322 | 0.13329 | 0.1385 |
| cost of energy production in Euros/kWh | 0.08755 | 0.08652 | 0.10404 | 0.09263 |
| Non imported energy production-security (%) | 45.03812 | 45.03812 | 45.03812 | 45.03812 |
| Renewable energy share in energy and electricity | 53.03285 | 53.02989 | 69.03777 | 71.86052 |
| Non Carbon energy share in energy and electricity | 53.03285 | 53.02989 | 69.03777 | 71.86052 |
| Biofuels share in primary energy supply (%) | 58.14401 | 58.13912 | 78.69299 | 81.31358 |

## C2 Multi-criteria analysis

The following sustainability indicators were used for multi-criteria analysis of Limina’s case:

fuel resource indicator (kg/kWh)

cost of energy production (€/kWh)

total cost (M€)

Renewable energy share (%)

Emissions of GHG (kT CO2-eq)

Two sets of weights were used to rank the scenarios:

| Indicators | weights |
|---|---|
| fuel resource indicator (kg/kWh) | 0 |
| cost of energy production (€/kWh) | 0.2 |
| total cost (M€) | 0.2 |
| Renewable energy share (%) | 0.3 |
| Emissions of GHG (kT CO2-eq) | 0.3 |

Weighted performance

| **Scenario 1** | Scen 2 | Scen 3 | Scen 4 |
|---|---|---|---|
| **6.30842** | 6.19919 | 6.19919 | 5.95403 |

| Indicators | weights |
|---|---|

| | | | | | |
|---|---|---|---|---|---|
| fuel resource indicator (kg/kWh) | 0 | Weighted performance | | | |
| | | Scenario 1 | **Scen 2** | **Scen 3** | Scen 4 |
| cost of energy production (€/kWh) | 0.1 | | | | |
| total cost (M€) | 0.1 | 3.7123 | **4.25768** | **4.25768** | 4.00013 |
| Renewable energy share (%) | 0.1 | | | | |
| Emissions of GHG (kT CO2-eq) | 0.7 | | | | |

In the first instance, when cost is weighted more heavily, clearly a case of emission limits (Scenario 4), is the least desired. However, in the second instance, where emissions are weighted more, Scenario 4 still does not come out on top, with Scenario 3 tied with Scenario 2. Although Scenario 3 would technically be more advantageous because much less emissions are created (about 90 000 tonnes less). This shows that putting mandatory emission limits (Scenario 4) is not really necessary to achieve a GHG reduction benefit if the oil-price goes up very high.

Given the strong showing of PV and solar thermal, the proposed developments in Work Package 4 and 5 are in line. In terms of biomass-based electricity, the option, although technically available in the model, was not pursued.

## D. Partner No 4, MFKG, Knic- Kragujevac case study

### D1. Optimisation process

The optimization process has been implemented for 3 time periods each one corresponding to 5 years of energy planning and 4 time intervals for the formation of Load Duration Curves.

### D1.1 Scenario definition

Here, we define three scenarios, although we developed another 6 scenarios. The reason behind it is that the reported scenarios are these with the highest renewable share. Namely, the high renewable energy share is one of very important objectives of our work.

i) Scenario 1

- Centralized electricity production is used, giving electricity to the grid, by using coal electricity generators, hydro power, biomass, and biogas. They satisfy electricity demands of domestic, industrial, and agriculture energy sectors.
- Process heating in industry is done by natural gas and biogas (a substitution of natural gas with biogas for heating may be foreseen).
- Biomass, photovoltaic, and biogas are used for distributed production of electricity for waste water treatment and biogas plant energy sector.
- For waste water treatment sector, the heat demands will be covered by burning of biogas.
- District heating is used for domestic energy sectors with technologies to be compared for its production, such as coal and biomass burners.
- Space heating of domestic sector is also satisfied by biomass stoves and natural gas stoves.
- Domestic water heating was done by using electricity and it’s replaced by using solar energy.
- In agriculture sector, biomass and solar collector are used for technology.
- Primary energy source production is foreseen from sunflower crop and participation for bio-diesel production in the region. Diesel fossil fuel still plays a substantial role for non-agricultural traffic.
- Primary energy source production is also foreseen with biomass production from giant red for use as wood pellets and chips.

ii) Scenario 2

- Centralized electricity production is used, giving electricity to the grid, by using coal electricity generators, hydro power, biomass, and biogas. They satisfy electricity demands of domestic, industrial, and agriculture energy sectors.
- Process heating in industry is done by natural gas and biogas (a substitution of natural gas with biogas for heating may be foreseen).
- Biomass, and biogas are used for distributed production of electricity for waste water treatment and biogas plant energy sector.
- For waste water treatment sector, the heat demands will be covered by burning of biogas.

- District heating is used for domestic energy sectors with technologies to be compared for its production, such as coal and biomass burners.
- Space heating of domestic sector is also satisfied by biomass stoves and natural gas stoves.
- Domestic water heating was done by using electricity and it's replaced by using solar energy.
- In agriculture sector, biomass and solar collector are used for technology.
- Primary energy source production is foreseen from sunflower crop and participation for bio-diesel production in the region. Diesel fossil fuel still plays a substantial role for non-agricultural traffic.
- Primary energy source production is also foreseen with biomass production from giant red for use as wood pellets and chips.

ii) Scenario 3

- Centralized electricity production is used, giving electricity to the grid, by using coal electricity generators, hydro power, biomass, and biogas. They satisfy electricity demands of domestic, industrial, and agriculture energy sectors.
- Process heating in industry is done by natural gas and biogas (a substitution of natural gas with biogas for heating may be foreseen).
- Biomass, and biogas are used for distributed production of electricity for waste water treatment and biogas plant energy sector.
- For waste water treatment sector, the heat demands will be covered by burning of biogas.
- District heating is used for domestic energy sectors with technologies to be compared for its production, such as coal and biomass burners.
- Space heating of domestic sector is also satisfied by biomass stoves and natural gas stoves.
- Domestic water heating was done by using electricity and it's replaced by using solar energy.
- In agriculture sector, biomass and solar collector are used for technology.
- Primary energy source production is foreseen from sunflower crop and participation for bio-diesel production in the region. Primary energy source production is also foreseen with biomass production from giant red for use as wood pellets and chips.

D1.2 Constraints taken into account

The scenario follows the general constraints for specific technologies selected to be configured like availability of technologies, energy generation and consumption balancing according to the specific loads, Peak demand satisfaction, Plant facility operation limits, Limits on energy generation etc as described in D6.

Significantly, the following constraints were imposed on the 1st scenario optimisation process:

- Primary energy consumption: Upper bound of coal fuel consumption was set to 100,000 tones.
- Share of Renewable Energy produced in the system: A minimum RES share in the total power output in the system was set to 20%.

- Limits on renewable energy potentials: The RES potential was given ample.
- Emission limits: The total annual emission of each pollutant was given with an upper bound of 1000000t.

## D1.3 Optimised configurations – Outputs of the model

Running DOIRES for the above described scenario gave the following optimized configuration of technologies for which the additional power to be installed in the three time periods is given in Table 1.3.

The model chose to install additional power for coal electricity generator for heating of domestic hot water (3.93 MW), coal electricity generator for other needs (18.38 MW), hydropower for main grid (0.000286 MW), solar heating of hot water for domestic houses (3.04 MW), solar heating of hot water for public institutions (0.082 MW), space heating by biomass of domestic houses (0.0013 MW), biomass district heating (0.14 MW), process heating by natural gas (0.00115 MW).

The model has selected between possible combinations of specific technologies for satisfaction of specific loads, like 1) hydropower against coal, biomass, photovoltaics, 2) Solar heat against use of electricity for sanitary water, 3) biomass against coal for district heating, and 4) biomass against natural gas for space heating.

Some selected technologies competed over others. Not selected technologies to be installed were photovoltaics and use biodiesel.

All installations is suggested to be in the 1st time period

Table A1.3.1 Additional power to be installed in KW

| Additional Power to be installed in KW | Scenario 1 | Scenario 2 | Scenario 3 | |
|---|---|---|---|---|
| centr_Tech1_1 | 5833.874 | 18377.864 | | 18377.864 |
| centr_Tech1_2 | 3930.7 | 3930.7 | | 3930.7 |
| centr_Tech2_1 | | 0 | | |
| centr_Tech2_2 | | 0 | | |
| centr_Tech3_1 | 12543.99 | 0 | | |
| centr_Tech6_1 | 0.286 | 0.286 | 0.286 | |
| distr_Tech6_1_1 | | 0 | | |
| distr_Tech6_1_2 | | 0 | | |
| distr_Tech6_1_6 | | 0 | | |
| distr_Tech6_1_7 | | 0 | | |
| sanwater_Tech9_1_1 | 1912.45 | 3035.34 | 3035.34 | |
| sanwater_Tech9_2_6 | 51.75 | 82.49 | 82.49 | |
| district_Tech11_3_1 | 0 | 0 | | |
| spheating_Tech11_4_6 | 0 | 1.314 | 1.314 | |
| district_Tech18_3_1 | 140.3 | 140.3 | 140.3 | |
| spheating_Tech19_4_6 | 1.15 | 0 | | |
| processheating_Tech19_5_7 | 1.15 | 1.15 | 1.15 | |
| processheating_Tech20_5_7 | 0 | 0 | | |
| diesel_Tech16 | 17937.7 | 17937.7 | | |

Other outputs of the model are given in Table A1.3.2 below

Table A1.3.2 Summary of results

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| total emissions in kt | 0 | 0 | 0 |
| total cost in Millions Euros | 2321.16796 | 5776.74722 | 664.17104 |
| total produced energy in GWh | 241986.24 | 604919.61 | 348729.03 |
| total produced res energy in GWh | 11226.708 | 28085.328 | 28085.328 |
| Fuel resource indicator in kg/kWh | 0 | 0 | 0 |
| cost of energy production in Euros/kWh | 0.00959 | 0.00955 | 0.0019 |
| Non imported energy production-security (%) | 4.6394 | 4.63956 | 8.04797 |
| Renewable energy share in energy and electricity (%) | 4.6394 | 4.64282 | 8.05362 |
| Non Carbon energy share in energy and electricity (%) | 4.6394 | 4.63956 | 8.04797 |
| Biofuels share in primary energy supply (%) | 0 | 0 | 0 |

D2 Multi-criteria analysis

The following sustainability indicators were used for multi-criteria analysis of Knic-Kragujevac case:

total cost (M€)

Renewable energy share (%)

By weighting differently the criteria we run twice multi-criteria analysis and we got the following results:

| Indicators | weights | Weighted performance | | |
|---|---|---|---|---|
| | | Scenario 1 | Scenario 2 | Scenario 3 |
| total cost (M€) | 0.5 | 0.452 | 0.114497 | 1.11447 |
| Renewable energy share (%) | 0.5 | | | |

| Indicators | weights | Weighted performance | | |
|---|---|---|---|---|
| | | Scenario 1 | Scenario 2 | Scenario 3 |
| total cost (M€) | 1 | -0.454 | -1.129 | -0.129 |
| Renewable energy share (%) | 0 | | | |

| Indicators | weights | |
|---|---|---|

| | | Weighted performance | | |
|---|---|---|---|---|
| | | Scenario 1 | Scenario 2 | Scenario |
| total cost (M€) | 0 | 1.359 | 1.359 | 2.358 |
| Renewable energy share (%) | 1 | | | |

The results shows that there is no conflicts among applied criteria in Serbia,. In the all cases, multi-criteria analysis was in favor of scenario 3. Scenario 3 would minimize total costs and maximize renewable energy use.

## E. Partner No 5, MAGA, Podbelasica case study

### E1. Optimisation process

The optimization process has been implemented for 3 time periods each one corresponding to 5 years of energy planning and 4 time intervals for the formation of Load Duration Curves.

#### E1.1 Scenario definition

i) Scenario 1

- Geothermal potential is used for heating of domestic sector with defined thermal power demand.
- Geothermal potential is used for heating in agricultural sector with defined thermal power demand.

ii) Scenario 2

In order to force new installations for RE, the thermal energy used from geothermal potential is forced to increase in this 2nd scenario that increase used energy about 40% per year for each technology (domestic heating and agricultural heating).

#### E1.2 Constraints taken into account

The scenario follows the general constraints for specific technologies selected to be configured.
In fact, for planed RE sources in case of MAGA, geothermal resources have minimum constraints in line to optimization model:

- emission of CO2 is zero that we don't have emission limits and
- limits of renewable energy potentials are on high level its means that in this case its reach sources with two holes with 22 MW thermal power in total and about 64000 MWh produced thermal energy / year.

Significantly, the following constraints were imposed on the both scenarios' optimisation processes:

i) Scenario 1

- Limits on renewable energy potentials: The RES potential was given ample.

ii) Scenario 2

This scenario uses Scenario 1 as a base with increase of power energy demand in order to force new installations for RE.
In inputs related to general constraints applied for all cases, in this 2$^{nd}$ scenario we have:

- Constraint - Power generation and consumption balancing; Demand for thermal power is increase for about 40%.

- Constraint - Limits on renewable energy potentials: The RES potential was given ample.

## E1.3 Optimised configurations – Outputs of the model

Running DOIRES for the above described scenarios gave the following optimised configuration of technologies for which the additional power to be installed in the three time periods is given in Table E 1.3.1.

Table E 1.3.1 Additional power to be installed in MW

| Additional Power to be installed in MW | | | |
|---|---|---|---|
| total capacity | | Scenario 1 | Scenario 2 |
| spheating_Tech8_1_1 | | 23783,4 | 35259 |
| heatdemands_Tech8_6_3 | | 10860 | 10860 |
| additional power to be installed | | 1 | 2 |
| spheating_Tech8_1_1 | | 9303,4 | 11475,6 |
| heatdemands_Tech8_6_3 | | 0 | 0 |
| power output | | 1 | 2 |
| spheating_Tech8_1_1 | | | |
| | 1 | 10860 | 10860 |
| | 2 | 16100 | 16100 |
| | 3 | 22200 | 22200 |

Other outputs of the model are given in Table E1.3.2 below:

Table E1.3.2 Summary of results

| | **Scenario 1** | **Scenario 2** |
|---|---|---|
| total emissions in kt | 0 | 0 |
| total cost in Millions Euros | 31.49858 | 11.74811 |
| total produced energy in GWh | 448.7736 | 228.444 |
| total produced res energy in GWh | 448.7736 | 228.444 |
| New Job Indicator (jobs) | 341.38 | 69.82 |
| cost of energy production in Euros/kWh | 0.07019 | 0.05143 |
| Non imported energy production-security (%) | 100 | 100 |
| Renewable energy share in energy and electricity (%) | 100 | 100 |
| Non Carbon energy share in energy and electricity (%) | 100 | 100 |
| Biofuels share in primary energy supply (%) | 0 | 0 |

## E2 Multi-criteria analysis

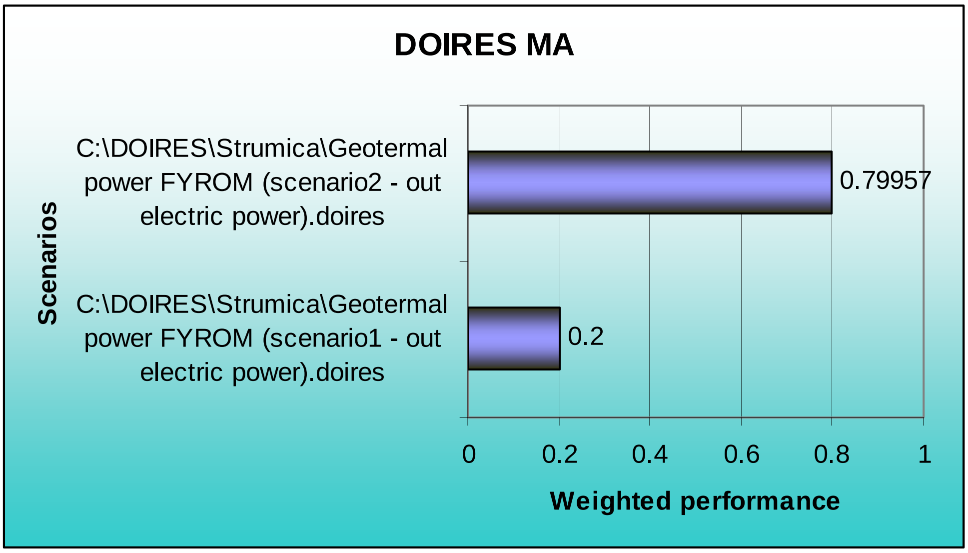
For multi-criteria analysis its given economic indicator and social indicator - new job indicator for both technologies (0.1 for domestic and 0.02 for geothermal energy).
The following sustainability indicators were used for multi-criteria analysis of Strumica case:

Social indicator
(New job (person/KW)

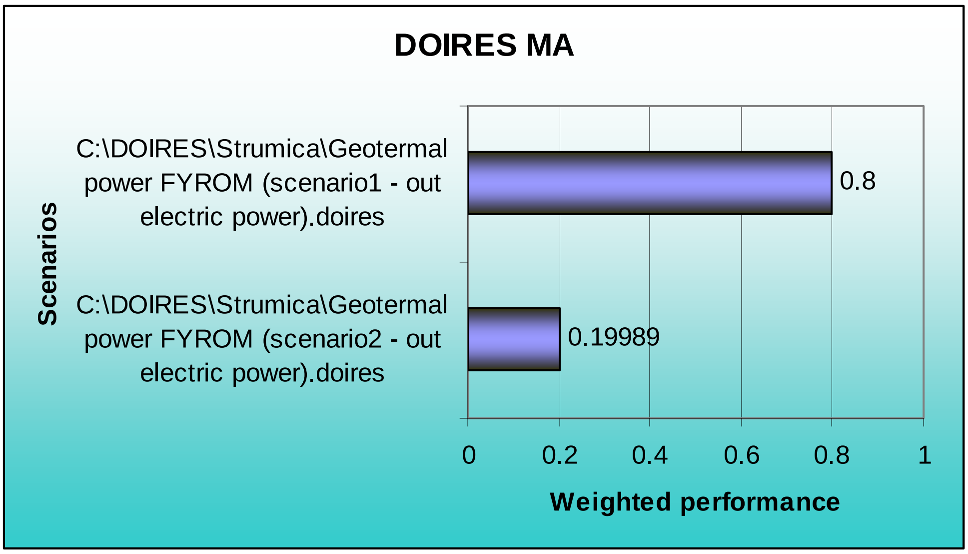
Economic indicator
(Cost of energy production €/kWh)

By weighting differently the criteria we run three times multi-criteria analysis and we got the following results:

| Indicators | weights | Weighted performance | |
|---|---|---|---|
| | | Scenario 1 | **Scenario 2** |
| Social indicator (New job (person/KW) | 0.2 | 0.2 | 0.79957 |
| Economic indicator (Cost of energy production €/kWh) | 0.8 | | |




| Indicators | weights | Weighted performance | |
|---|---|---|---|
| | | **Scenario 1** | Scenario 2 |
| Social indicator (New job (person/KW) | 0.8 | 0.8 | 0.2 |
| Economic indicator (Cost of energy production €/kWh) | 0.2 | | |




| Indicators | weights | Weighted performance | |
|---|---|---|---|
| | | **Scenario 1** | Scenario 2 |
| Social indicator (New job (person/KW)) | 0.5 | 0.5 | 0.499 |
| Economic indicator (Renewable energy share (%)) | 0.5 | | |

The results give a idea that in case of dominant economic indicator better is 2nd scenario with bigger exploitation of RE sources. In case of high weight of social indicator we have optimal situation in 1st scenario.

In both cases multi-criteria analysis was in favour of scenario1 or scenario2, which means that the decision is depended of which indicator aspect will be primary – social or economic.

## F. Partner No 6, PUT, Bregu case study

For Bregu case study two scenarios of IRES were compared in multi-criteria analysis.

### F1. Optimisation process

The optimization process has been implemented for 3 time periods each one corresponding to 3 years of energy planning and 4 time intervals for the formation of Load Duration Curves.

#### F1.1 Scenario definition

i) Scenario 1

- Centralized electricity production is used, giving electricity to the grid, for the production of which, technologies selected are wind turbines and hydro power to satisfy electricity demands of domestic, industrial and agriculture energy sectors.
- Domestic sector, Industry sector and Agriculture sector do not satisfy their electric power demands only by the grid, but a distributed energy production is also used with fossil fuel generators (a substitution of fossil fuel generators may be foreseen).
- Space heating needs for domestic sector are satisfied by biomass, while heat needed for sanitary water is partly produced by solar collectors. In industry sector, together with solar collectors are used fossil fuel boilers.
- A great part of need for heat for agriculture sector is supplied by solar collectors.
- Actually more than half of electrical energy needs for all three sectors (domestic, industry and agriculture) is imported from national grid. However it remains always problematic due to insufficient capacity and low quality, especially during tourist period.

ii) Scenario 2

Scenario 2 is the same as scenario 1 with a change in technologies used to supply energy for domestic needs.

- Space heating needs for domestic sector are no more satisfied by biomass but by solar collectors.
- Electrical energy for domestic use produced by diesel engines is supplied by the grid.
-

#### F1.2 Constraints taken into account

The scenario follows the general constraints for specific technologies selected to be configured like availability of technologies, energy generation and consumption balancing according to the specific loads, Peak demand satisfaction, Plant facility operation limits, limits on energy generation etc as described in D6.

Significantly, the following constraints were imposed on the 1st scenario optimisation process:

- Primary energy consumption: Upper bound of crude oil fuel consumption was set to 10,000 tones.
- Share of one technology to satisfaction of specific load level: Specific technology's of diesel generators power output was set to be up to no limit percentage of total power output from the sum of technologies that participate in the load satisfaction, to which the particular technology corresponds.
- Share of Renewable Energy produced in the system: A minimum RES share in the total power output in the system was set to 5, 6 and 7.2 percent, with a growth rate of 20% every year.
- Limits on renewable energy potentials: The RES potential was given ample.
- Emission limits: The total annual emission of the *r*-th pollutant was given with an upper bound loose.

On the 2nd scenario optimization process the above constraints were differentiated according to:

- Primary energy consumption: Upper bound of crude oil fuel consumption was set to 1,000 tones. The same upper bound is set to diesel thermal (much stricter than in scenario 1). Upper bound to use of wood is set to zero.
- Share of one technology to satisfaction of specific load level: Specific technology's of diesel generators power output was set to be up to 10% of total power output from the sum of technologies that participate in the load satisfaction, to which the particular technology corresponds.
- Share of Renewable Energy produced in the system: A minimum RES share in the total power output in the system was set to 20 % with a growth rate of 20 % up to third year.
- Emission limits: The total annual emission of the *r*-th pollutant was given with an upper bound 70 % stricter than 1st scenario.

## F1.3 Optimized configurations – Outputs of the model

Running DOIRES for the above described scenario gave the following optimized configuration of technologies for which the additional power to be installed in the three time periods is given in Table 1.3.1 and total power to be installed in Table 1.3.2

The model chose to install additional power for diesel generators (362.3 kW) for distributed electricity generation, hydropower (7.6 MW) for centralized electricity generation. For heating, geothermal heating system for space heating-cooling of 3.747 MW. Solar collectors' capacity for sanitary water of domestic sector will increase by 2.05 MW.

Table F1.3.1 Additional power to be installed in kW

| | Scenario 1 | Scenario 2 |
|---|---|---|
| distr_Tech1_4_1 | 7.8 | 0 |
| distr_Tech1_5_2 | 123.5 | 28.125 |
| distr_Tech1_6_3 | 231 | 53.25 |

| | | |
|---|---|---|
| centr_Tech4_1 | 0 | 0 |
| centr_Tech6_1 | 7601.1 | 3121.86667 |
| sanwater_Tech9_7_1 | 1155.2 | 577.60033 |
| sanwater_Tech9_8_2 | 896.5 | 448.23915 |
| heatdemands_Tech9_5_3 | 467.9 | 287.39107 |
| heatdemands_Tech10_4_2 | 27.5 | 0.225 |
| spheating_Tech11_6_1 | 1200 | 0 |
| diesel_Tech16 | 84.2 | 28.125 |

Table F1.3.2 Total power to be installed in kW

| | Scenario 1 | Scenario 2 |
|---|---|---|
| distr_Tech1_4_1 | 13.8 | 0 |
| distr_Tech1_5_2 | 287.5 | 353.6 |
| distr_Tech1_6_3 | 575 | 707.25 |
| centr_Tech4_1 | 2500 | 2500 |
| centr_Tech6_1 | 9051.1 | 12173.0 |
| sanwater_Tech9_7_1 | 1605.2 | 2407.8 |
| sanwater_Tech9_8_2 | 1246.7 | 1869.7 |
| heatdemands_Tech9_5_3 | 667.9 | 1055.3 |
| heatdemands_Tech10_4_2 | 57.5 | 70.7 |
| spheating_Tech11_6_1 | 2300 | 0 |
| diesel_Tech16 | 794.2 | 1191.4 |

Table F1.3.3 Summary of results

| | Scenario 1 | Scenario 2 |
|---|---|---|
| total emissions of GHG in kt CO2 eq | 42.05 | 29.6 |
| total cost in Millions Euros | 59.70 | 57.4 |
| total produced energy in GWh | 339.9 | 313.3 |
| total produced res energy in GWh | 293.1 | 266.8 |
| Fuel resource indicator in kg/kWh | 0.05 | 0.03 |
| cost of energy production in Euros/kWh | 0.18 | 0.18 |
| Non imported energy production-security (%) | | |
| Renewable energy share in energy and electricity (%) | 86.2 | 85.2 |
| Non Carbon energy share in energy and electricity (%) | 86.2 | 85.2 |
| Biofuels share in primary energy supply (%) | 43.3 | 0 |

## F2 Multi-criteria analysis

The following sustainability indicators were used for multi-criteria analysis of Bregu case:

fuel resource indicator (kg/kWh)
cost of energy production (€/kWh)
total cost (M€)
Renewable energy share (%)
Emissions of GHG in kT CO2 equiv

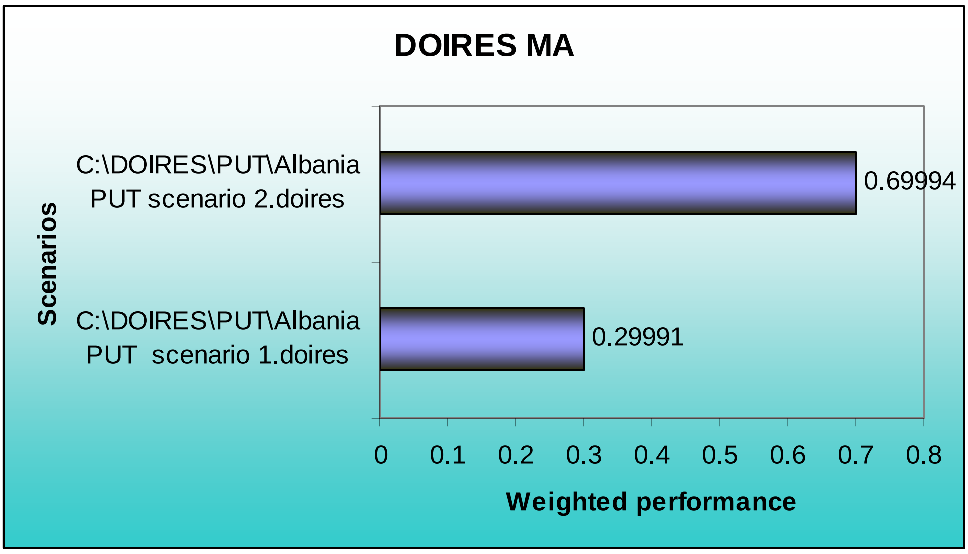
By weighting differently the criteria we run twice multi-criteria analysis and we got the following results:

| Indicators | weights |
|---|---|
| fuel resource indicator (kg/kWh) | 0.1 |
| cost of energy production (€/kWh) | 0.3 |
| total cost (M€) | 0.3 |
| Renewable energy share (%) | 0.2 |
| Emissions of GHG in kT CO2 equiv | 0.1 |

| Weighted performance | |
|---|---|
| Scenario 1 | **Scenario 2** |
| 0.5 | 0.5 |

| Indicators | weights |
|---|---|
| fuel resource indicator (kg/kWh) | 0.1 |
| cost of energy production (€/kWh) | 0.1 |
| total cost (M€) | 0.1 |
| Renewable energy share (%) | 0.2 |
| Emissions of GHG in kT CO2 equiv | 0.5 |

| Weighted performance | |
|---|---|
| Scenario 1 | **Scenario 2** |
| 0.299 | 0.699 |




In the second scenario we removed use of wood from heat demands for domestic heat and substituting with energy from solar collectors and electrical energy. This resulted in an important decrease of total emission of GHG and a decrease of total cost, without any notable increase of cost for unit of energy. This result gives a hint toward scenario two, however no definitive reliable decision can taken due to frequent changes of the price of imported energy.