Industrial Model for Energy Efficiency Strategies in Slovenia

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ABSTRACT

Within the strategic study of Integrated Resource Planning for Rational Use of Energy in Slovenia, the industrial sector was analyzed in detail. The simulation model of industry has been designed for the MESAP PlaNet computer tool as a part of a "Reference energy system" of Slovenia. MESAP (Modular Energy System Analysis and Planning) is a toolbox for integrated energy and environmental planning. Its simulation module, called PlaNet, is designed to analyze and simulate the energy demand and energy supply systems including their cost and environmental impacts. The paper describes the basic equation system of the PlaNet flow calculations. The industrial sector is presented as linear network techno-economic model, which enables detailed energy flow analysis by specific technology processes, as well as balance accounting, cost and emissions calculation required for strategic planning. Energy saving potential in industry is evaluated for different energy intensive processes: arc furnaces in the steel industry, boilers, electrical motors, compressed air system, and thermal process for production of paper and pulp and combined heat and power production (CHP). A scenario of economic development and growth of physical product of industry in Slovenia is developed. Estimates of energy use in industry are based on physical production and not on value added. Two strategies, each with different intensities of implementation of energy efficient technologies and measures, are compared (reference and intensive) for the period 1997 to 2020. Penetration of improved technologies is higher in the Intensive strategy, based on the economic conditions established by the energy policy invoked. The paper presents a comparison of the results of energy use and emissions and an evaluation of potential energy savings for both strategies.

Introduction

Energy efficiency is an important means of realizing the established triad objectives of the energy policy in the European Union: security of supply, competitiveness and sustainability, as measured by a minimum of environmental impact (Salas and Lambert 1999). The most immediate direct environmental benefit of more efficient energy use is a reduction in the use of resources and emissions of many pollutants as well as of CO_2.

An integrated resource planning approach to the problem of efficient use of energy in Slovenia has been applied in several studies (IRP Slovenia 1996 - 1997; SMEMM & ICL 1999; Tomsic et al 1999). The energy policy problem was structured as a multicriterial decision problem on the national level under the following goals / criteria:

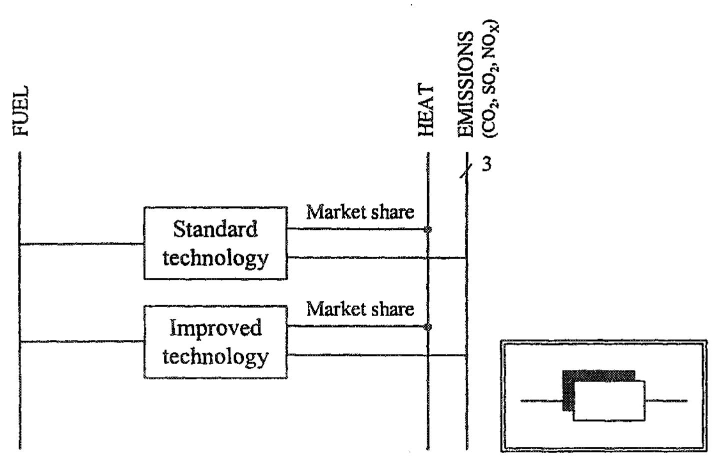
1. increase of economic efficiency (system costs, profit, etc.),

2. increase of reliability and efficiency of supply (LOLE, import dependency, etc.),
3. reduction of environmental pollution (emissions of SO_2, CO, NO_X, N_2O),
4. social acceptability (unemployment, no. of new jobs, etc.).

End use in some sectors, especially industry and households, were considered in detail. A modeling approach to energy processes in industry and the results of simulations that were used in the multicriterial strategy evaluation are presented.

Modeling Tools

An energy system analysis toolbox, MESAP (Modular Energy System Analysis and Planning Environment) for integrated energy and environmental planning, has been developed at the Institute for Energy Economics and the Rational Use of Energy (IER), University of Stuttgart (MESAP 1999). It has been created to conduct medium to long term policy analysis for local, regional and global strategies concerning energy and environmental systems. Its simulation module, called PlaNet (Planning Network), is designed to analyze and simulate the energy demand and energy supply systems including their costs and environmental impacts. PlaNet is an accounting type linear simulation model that uses a scenario technique to explore the impact of different political strategies. Several other tools from the MESAP toolbox, including optimization modules can be applied to the model developed for PlaNet.



efficiency$_{IMPR}$ > *efficiency* $_{STAND}$

specific emissions $_{IMPR}$ < *specific emissions*$_{STAND}$

Figure 1. Technology Analysis Approach - Modeling by a Parallel Process

MESAP enables a technology-oriented modeling approach where several competitive technologies that supply energy services are represented with parallel processes (Figure 1). Process input and output flows are connected to commodities (vertical lines) and all together form a network model named Reference Energy System (RES). The volume of a service supplied by a technology (heat, for example) is defined by market shares[1] that split the service demand (commodity) between the processes (technologies) that demand this service. Process flow relations are defined by set of linear equations, freely defined for each process[2], for example from Figure 1:

$$Heat = Fuel * Efficiency$$

$$Emissions = Fuel * Emission\ factor$$

In the studies referred to earlier, a complete reference energy system, covering all the demand and supply sectors of Slovenia, was implemented. In this article, we will focus on describing the simulation results in the industrial sector.

Reference Energy System for Industry

The manufacturing industry in Slovenia is dissaggregated to 14 branches according to the Standard Classification of Activities (based on Nace Rev. 1). Three energy intensive sub-branches are dealt with separately: steel and ferro-alloys production (DJ_S), aluminum production (DJ_{AL}), and pulp and paper production ($DE_{21.1}$). The main structure of the industrial model (SLO_I) presented in the form of the reference energy system is shown in Figure 2.

The model includes 170 processes and 60 commodities. Industrial technology processes implemented in the RES model for all branches are divided into five groups:

1. Electrical motors:
   - Variable Speed Drive
   - Standard / Improved motor technology
2. Compressed air systems:
   - Standard / Improved (implemented energy efficiency measures)
3. Electrical processes & appliances and other electricity use,
4. Thermal processes,
5. Space heating (season temperature correction process -climate),
6. Non-energy use.

Additional processes for energy intensive sub-branches are:

a Aluminum electrolysis (DJ_{AL}),

b Electrical arc furnaces processes DJs

- Standard / Improved (implemented energy efficiency measures)

c Paper and pulp production thermal processes

- Standard / Improved (implemented energy efficiency measures)

Aggregated processes for the whole industry are:

1. Heat and steam boilers:
   - by fuel type, standard / improved (implemented energy efficiency measures)

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[1] Market shares are exogenously defined by other tools and are input parameters for simulation.

[2] The number of equations depends on the number of fuels (energy carrier) and emissions modeled in each process.

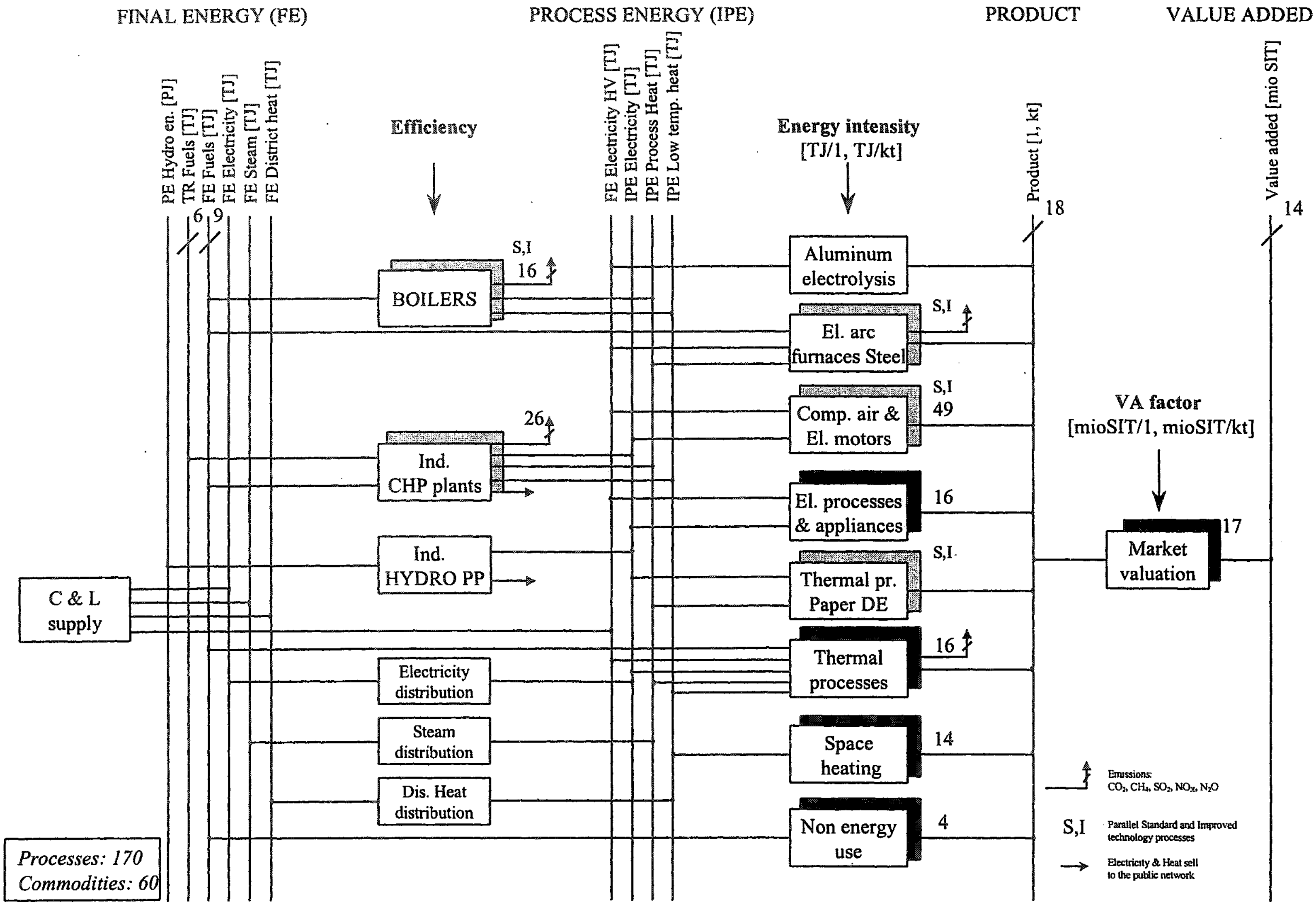

Figure 2. The Main Structure of the RES of Industrial Sector

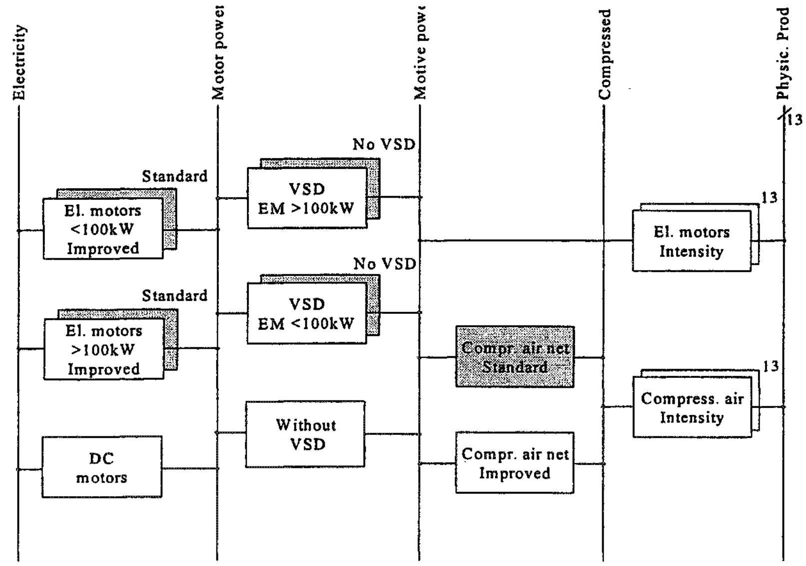

Figure 3. RES of Industrial Electrical Motors and Compressed Air Systems

2. Industrial CHP
    - by technology (existing / new) and fuel type

3. Industrial small hydropower plants.

A sub-model of electrical motors and compressed-air systems (technology part aggregated for whole sector) is shown in Figure 3. Electrical motors (EM) are grouped by type, into asynchronous electrical motors and other motors (DC, etc), by size, into classes below and over 100kW (standard and improved technology), and with optional variable speed drives (VSD).

Value added typically drives econometric models of energy consumption. As Slovenia is a transition country, energy service demand is better correlated with physical product growth than with value added because value added will grow faster than the volume of physical product. For this reason, we decided to add an additional commodity level using physical products (expressed as index or in kilotons of aluminum, steel, or paper products per year). For each industrial sub-sector, we defined a "market valuation" process (Figure 4). Expectations regarding the ratio between value added and physical product are provided by comparative analysis between the present situation and possible development of terms of trade for each sector.

For industrial production processes, the energy intensity is defined as the ratio between fuel or energy (carrier) consumption and the physical product of industrial (sub) branch for each type of fuel or energy used.

Direct electricity consumers in industry (five companies in three sub-branches on the transmission networks) are treated separately. We used expert judgment to divide the available data on fuel consumption to industrial branches as:

- fuels used in industrial processes (thermal processes),

- fuels used in small-scale industrial boilers for producing low-temperature and process heat for industrial processes (thermal processes and space heating processes).

Scenario and Strategies

Scenario of Economic Development

The scenario of economic development of Slovenia is adopted from the scenario used in previous studies (SMEEM & ICL 1999; Strmsnik 1995; Strmsnik et al. 1999). In the planning period 1997 – 2020, the average annual value added growth is presumed to be 3,6% in Slovenia. Presumed sectoral breakdown of GDP at the end year 2020 is:

- Service sectors, 72,5%,
- Industry (all production sectors), 25%,
- Agriculture, 2,5%.

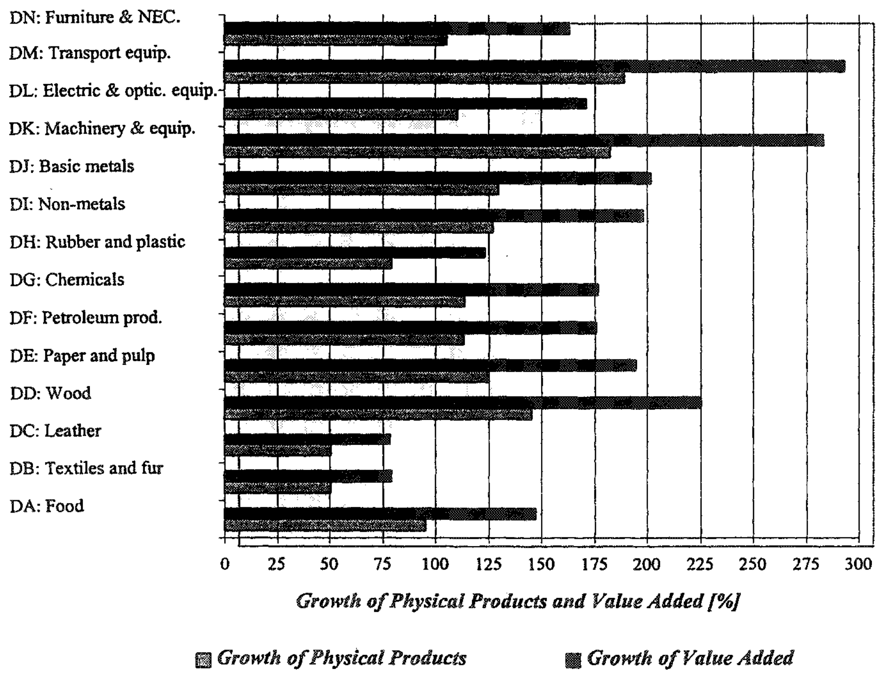

Figure 4. Growth of Value Added and Physical Products in Industry to 2020 based on 1997

The estimated average growth of physical products in industry is 2,4% per year. It varies from –1% to 4,7% yearly by branches and is considered as an appropriate proxy for the energy services demand. The assumed growth of the value added and physical product of manufacturing industry input data for the economic development scenarios are presented in Figure 4.

Energy Efficiency Strategies

Two strategies with different intensities of implementation of energy efficient technologies and measures are proposed: 'Reference-REF' and 'Intensive-INT'. Based on economic conditions established by respective energy policies, penetration of improved technologies is considerably higher in the Intensive strategy.

- **Reference strategy-REF:** Energy efficiency measures are similar to the present situation with minimal energy efficiency programs, at the level of general promotion only.
- **Intensive strategy-INT:** Cost effective potential at the demand side is stimulated to be achieved with higher speed and higher capital intensity to gain cost effectiveness and additional environmental benefits. Some instruments for the support of high speed penetration of energy efficiency measures and technologies are considered:
    - additional energy tax (20%) for services and households sectors,
    - facilities of taxes by use of co-operative instruments,
    - financial stimulation and subsidies for investments in energy efficiency measures and technologies,
    - demand side management programs.

Energy Saving Potential

Energy efficiency strategies for the industry consist of sets of energy efficiency measures based on the results of several studies (ETSU and IJS 1996; Kozuh, Spendal and Selan 1997) and assessment of experts.

The potential energy savings for each technology are identified using the analytical methods with a "least cost" financial analysis approach. A benefit of this approach is that it allows the identification of the scope for cost-effective energy savings as a function of supplied fuel prices and differing investment criteria.

The technical measures for improving energy efficiency considered as cost-effective for different technologies are:

- **Electric arc furnaces (steel production):** scrap preheating, scrap selection, oxy-fuel burners, additional sidewall burners and auto-slagging system.
- **Paper making processes (drying and other):** improvement drying in paper making and reduced size wetting in paper finishing, humidity control of pre-drying, nipco roll and impulse drying in the press section, humidity control of post-drying, reduced size wetting in presses.
- **Boiler plants (all industry):** improvement measures for all boilers: variable speed drives, oxygen trimming, decentralized boiler house, condensate return, chain grate improvements of coal boilers, condensing economizers of gas boilers and water injection systems, spray recuperation and fuel additive of oil fired boilers.
- **Electrical motors and drives (all industry):**

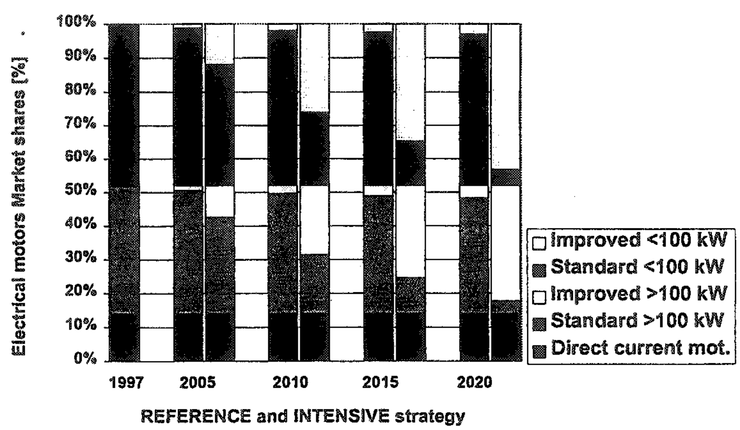

Figure 5. Electrical Motors Penetration by Strategies (Market Shares)

replacing of old motors with new more efficient motors and installation of suitable variable speed drive –VSD (frequency inverter).

- **Compressed air systems (all industry):** improved control systems, better maintenance and operation and reduction in waste air due to inadequate maintenance and leaks, reduction of pressure dropping and building of air valve sub-systems for separation.

Table 1. Energy Saving Potential And Efficiency of Standard and Improved Technologies

	Current energy consumption (PJ/a)	Cost effective potential (PJ/a)	Efficiency of standard process	Efficiency of improved process
EAFs - Steel industry	0,88	0,31	2,06 TJ/kt	1,3 TJ/kt
Thermal process in paper industry	3,49	1,65	5,88 TJ/kt	3,66 TJ/kt
Electrical motors (all branches) • Compressed air • Other drivers	9,11 1,79 7,32	0,61	Efficiency 82 – 92%	Imp.Efficiency EM: + 4% VSD: +32%
Compressed air systems	(1,79)	0,36	Intensity = 1	Intensity = 0,8
Boilers (all branches)	17,68	1,17	Efficiency 72 – 85%	Imp. Efficiency +5 - 15%
Total	**31,16**	**4,09**		

The model's evaluation of potential to save energy in industry proves to be cost-effective at 1997 energy price levels with an internal rate of return of 25%. Table 1 presents the energy saving potential in industry and the efficiency or specific energy consumption (SEC) of standard and improved technologies. We consider the "cost effective potential" as the possible energy saved, achieved the penetration of improved technologies and calculated at the assumed economic criteria (IRR, energy prices).

We assumed that all industrial processes not included in Table 1 average a 12% efficiency improvement (0.5% p.a.) for the planning period. The penetration of energy efficient technologies depends on the strategies applied. Figure 5 presents the penetration of efficient and standard electrical motors by strategy for every year of the planning period.

Industrial Combined Heat and Power (CHP)

CHP technology is generally accepted as offering large opportunities for primary energy saving in industry. Nominal installed capacity of industrial CHP units in the year 1997 was 117 MW, most as steam turbines and some as

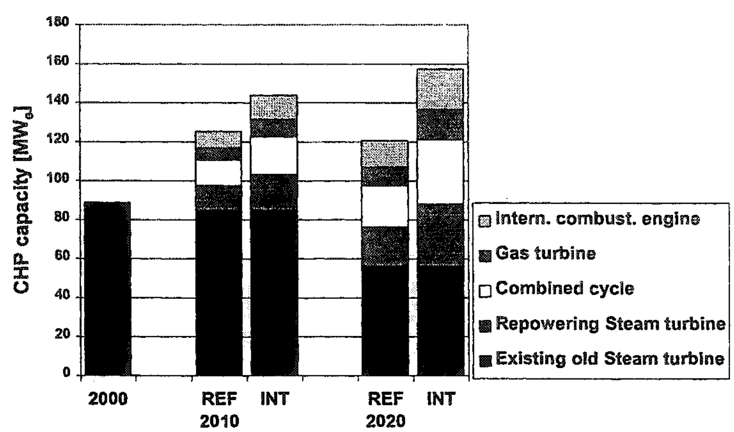

Figure 6. CHP Capacity Development by Strategies

steam engines. Yearly electricity production of 305 GWh shows lower operation capacity (around 87 MW). Most existing CHP units are approaching the end of their useful lifetime.

Economic potential for industrial CHP (ETSU and IJS, 1996) is estimated to 190 MW (90 MW in existing CHP locations and 100 MW in new locations). Future CHP development intensity described by both strategies (Figure 6) includes:

- repowering of existing steam turbines by additional gas turbines, and
- new combined cycle, gas turbines and internal combustion engine units.

Results of Simulation

Final Energy Consumption

Figure 7 shows the expected final energy consumption and value added (VA) in industry for both strategies (reference and intensive) over the modeling period. Final energy consumption in the Reference strategy grows 5,2% or 3,0 PJ whereas it is decreased 1,9% or 1,1 PJ/a in the Intensive strategy for the period 1997-2020.

Energy savings under the Intensive strategy are 7% or 4.1 PJ compared to the Reference strategy.

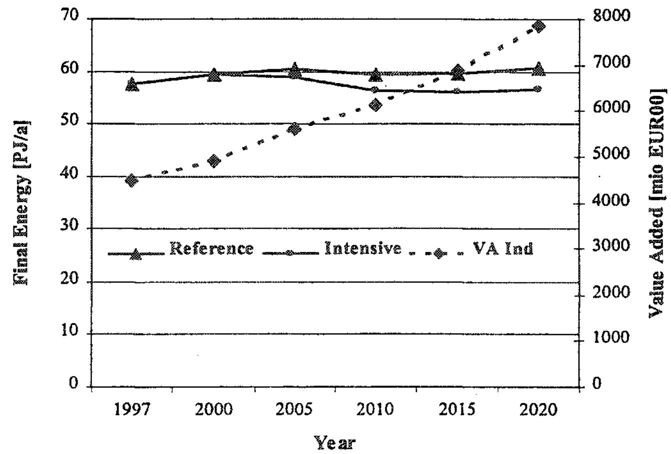

Figure 7. Final Energy Consumption and Value Added in Industry by Strategies

Electricity consumption. Electricity consumption growth over the modeling period when compared to the base year is 8,7% or 430 GWh/a in Reference and -4,1% or 203 GWh in the Intensive strategy (Figure 8).

Electricity consumption is reduced 12,7% or 633 GWh/a in the Intensive strategy when compared to the Reference strategy.

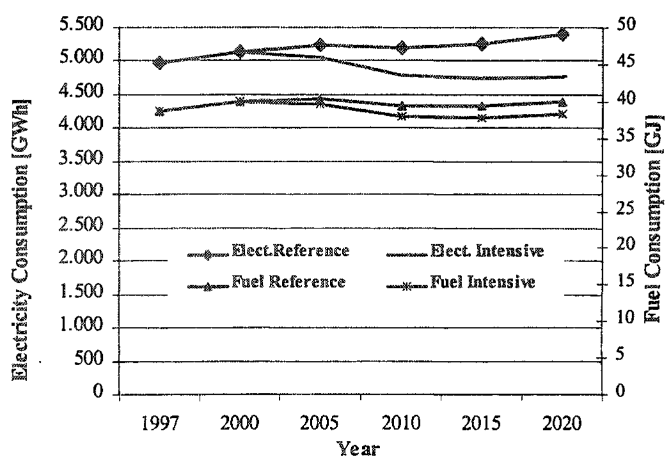

Figure 8. Electricity and Fuel Consumption in Industry by Strategies

Fuel consumption. Fuels use declines 0.4 PJ or 1 % in the intensive strategy and increases 1,4 PJ or 3,6% in the Reference strategy by 2020 (Figure 8). The difference between strategies is 1,8 PJ or 4,6% compared to the Reference strategy in 2020.

Energy Saving

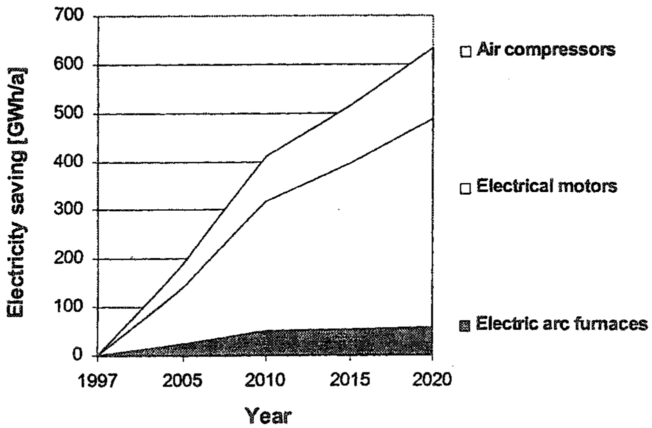

Figure 9. The Reduction of Electricity Consumption (Difference Between Strategies)

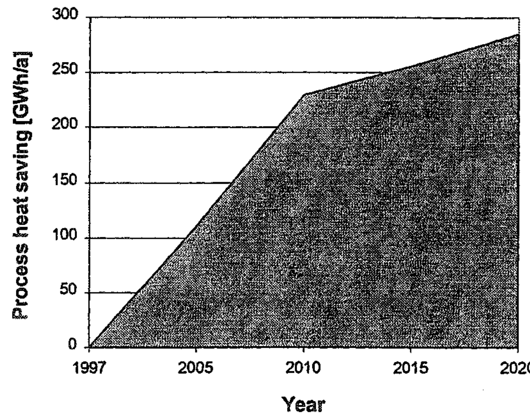

Figure 10. The Reduction of Process Heat Consumption in Paper Making (Difference Between Strategies).

Electricity saving. The biggest electricity savings are expected from improved electrical motors technologies including variable speed drive implementation (431 GWh) followed by the compressed air systems (145 GWh) and electrical arc furnaces (58 GWh) (Figure 9).

Process heat saving. The consumption of process heat in paper making in the year 2020 is reduced 27,6% or 285 GWh (or the process heat saving) in the Intensive strategy when compared to the Reference strategy (Figure 10).

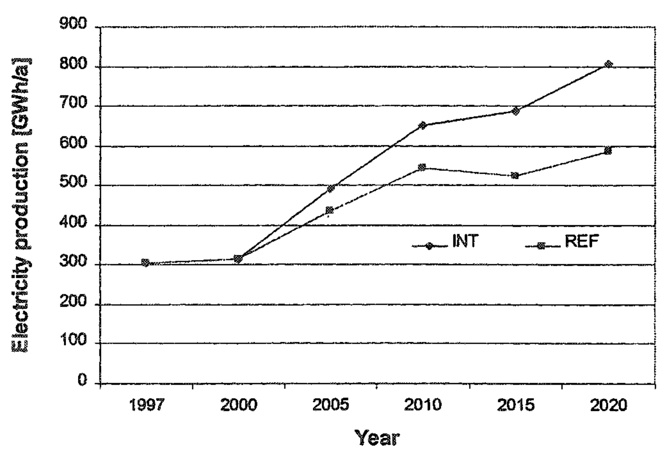

Figure 11. Total Industrial CHP Electricity Production from CHP in industry by Strategies

Electricity Production from CHP

The total industrial CHP electricity production (Figure 11) in the 2020 increases 165% or 502 GWh/a (compared to the base year) in the Intensive strategy, whereas in the Reference strategy the increase is only 92% or 281 GWh due to less favorable conditions assumed for CHP investment.

Carbon Dioxide Emission

Carbon dioxide (CO_2) emissions are directly proportional to fuel use and do not depend on the technologies[3]. Total CO_2 emissions in industry (including direct and indirect emissions caused by purchased electricity and heat from a public network) are presented in Figure 12. Emissions are increasing for 2 % (82 kilotons) over the planning period in the reference strategy where-as in Intensive strategy 7,8 % (-324 kilotons) decrease is achieved compared to the base year 1997.

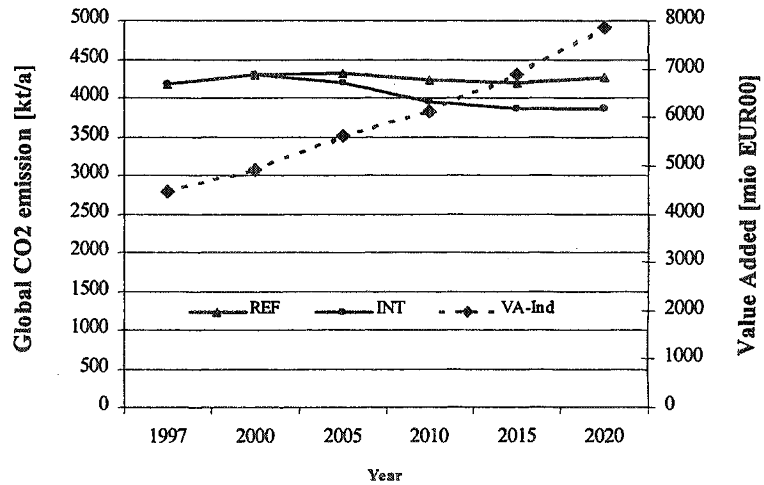

Figure 12. Total (Direct and Indirect) CO_2 Emission from Industry by Strategies.

The reduction of CO_2 emission in Intensive strategy in the year 2020 is 14 % (-406 kilotons) compared to the Reference strategy.

Conclusion

We used newly developed tools to analyze the impact on the penetration of several energy efficient technologies under different policy strategies. The industrial model used is built within the reference energy model of Slovenia (RES) to enable analysis of the impact of certain strategies at a global level. The Intensive energy efficiency strategy is preferable as it offers substantially lower use of final energy and a reduction of CO_2 emissions when compared to the Reference strategy at the same level of industrial output. Similarly, it was found that CHP capacity in the Intensive strategy will be appreciably higher than in the Reference strategy, which will further decrease primary energy demand. Increasing energy efficiency in industry requires investments in more energy efficient technologies supported by appropriate demand side management programs. Besides those described in this paper, the results of simulation also defines impacts on energy use, emissions and energy costs on the national level. In this analysis, we considered only currently available energy efficient technologies. In the future, new and upcoming technology improvements, as well as new energy efficiency measures should be included in the model and considered for further analysis.

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[3] The CO_2 emission factors are assumed to remain constant in all cases. No CO_2 cleaning technologies are expected to penetrate the market during the planning period.

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