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A new energy planning methodology for the penetration of renewable energy technologies in electricity sector—application for the island of Crete

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Abstract

This paper introduces a new energy planning methodology for more efficient promotion of renewable energy source (RES) technologies in the electricity sector. The proposed methodology has been developed under the European Programme ALTENER and the main outcome is a comprehensive computer simulation tool called INVERT. In this paper, a practical application of INVERT as well as a brief description will be presented through a detailed case study for the island of Crete. A number of different RES technologies, namely wind, small hydro, photovoltaic, biomass and solar thermal plants, have been simulated in sensitivity analyses based on new or additional RES promotion schemes. Simulation runs, considering existing and future electricity potential, have been carried out up to 2020. Transfer costs and CO_2 emissions of hypothesis scenarios have been compared with a reference scenario and the results will be presented and analysed.

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1. Introduction

Energy planning for renewable energy source (RES) penetration on a national or European level has been the core objective of a number of national and European projects (Zervos et al., 1998; Green-Net, 2002–2004; Green-X, 2002–2004). Comprehensive databases have been developed under Green-Net and Green-X projects, describing potentials and costs for different RES technologies in European countries. Both projects were aiming at enhancing the proportion of electricity from RES by applying a least-cost approach.

The perspectives of RES in Crete have been analysed from the Regional Energy Agency of Crete in cooperation with the National Technical University of Athens (NTUA). The study was focused on the exploitation of RES for electricity production for the period 1998–2010.

The major problem of Crete's energy system is the inability of the existing electrical system to meet the increasing demand, especially during the summer months. The existing autonomous electrical system faces a chronic problem caused by the high increase in electricity demand and the reluctance of the population to accept the installation of new thermal power stations. Innovative solutions are needed, which should provide both a sustainable development and a high standard of living. The use of RES can become the basis of a new alternative energy policy for the island and the use of appropriate available technologies can have multiple impacts on the environment.

The objective of this paper is to investigate the development of RES plants based on both current existing and new RES promotion schemes supported by the

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government in order to achieve a higher share of RES and a lower level of CO_2 emissions. Taking into account the RES potential for the island of Crete, the motivation of this work is to introduce new promotion strategies, which will result in maximum CO_2 reductions with minimum public expenses.

2. INVERT simulation tool

INVERT simulation tool (Stadler et al., 2005) is a comprehensive computer model supporting the design of energy planning for RES, with respect to electricity sector (RES-E).

In principle, INVERT allows simulating the existing building stock (heating, cooling, domestic hot water (DHW) systems, solar thermal), rational use of energy (RUE), as well as renewable energy sources according electricity supply (RES-E), heat production (RES-CHP) and bio-fuel production for any desired region. Due to the flexible design, INVERT allows comparative and quantitative sensitivity analyses of the interactions between RUE, RES-E, RES-CHP and bio-fuels as well as greenhouse gas (GHG) reduction for each selected region.

The basic idea of INVERT is to compare the spent money in the electricity or building sector with the corresponding reduction of CO_2 emissions in the same sector.

It evaluates the effects of different promotion schemes (investment subsidies, feed-in tariffs (FITs), tax exemptions, subsidy on fuel input, CO_2 taxes, soft loans and additional aside premium) on the energy carrier mix, CO_2 reductions and costs for society due to promoting certain strategies.

The INVERT simulation tool outputs for the relevant RES-E part in this paper are:

- CO_2 emissions (total reductions due to promotion schemes) (kton/yr),
- transfer costs for promoting RES-E technologies (Mio €/yr) and
- electricity production from RES-E power plants (GW h/yr).

Simulation runs for the case study of Crete include[2] the following RES technologies (Kranzl et al., 2004):

- wind-on-shore plants,
- small hydro stations,
- photovoltaic (PV) systems,
- biomass energy and
- solar thermal power plants.

[2]In principle, INVERT allows one to define any desired technology, but for the detailed investigation for the island of Crete, five technologies are most important.

The INVERT simulation tool provides a maximum flexibility regarding the specific data input of an individual region such as RES potentials, investment costs, efficiency or payback time. The main advantage of this tool is that the results of simulations are transparent; the user has the opportunity to see and explain the outcome of a simulation. The user may also modify model-specific definitions like simulation time frame, interest rates and technology data in a very flexible way. Furthermore, after the successful completion of a simulation—for a certain year—the user is able to change the promotion scheme settings for the next simulation year, based on the current situation in the investigated region.

In the following, the basic principles of INVERT will be presented and explained.

3. Methodology description

In this section, a brief description of the relevant RES-E part is given.

In the RES-E (as well as RES-CHP and bio-fuel part of INVERT) for each facility (“band”), the potentials and costs (short- /long-term marginal costs) for the electricity/ heat as well as bio-fuel production are gathered and sorted in a least-cost order. Each band is described by a certain set of parameters. For example, PV systems: all PV locations with the same full loud hour can be gathered and treated as one unique band. Of course, there are different costs for each plant in a band. In other words, in reality, we would obtain a continuous cost curve. However, for the modelling in INVERT, we use stepped discrete functions as an approximation (= static cost–resource curves) (Fig. 1).

The simulation tool considers also the effects of learning curves and market barriers which lead to the concept of dynamic cost–resources curves. These are applied in the simulation tool INVERT. The market barriers reduce the potential and the learning curves reduce the costs of the static cost–resource curve as indicated by the “dynamic cost–resource curve for a certain year”.

It is assumed that all RES-E bands get installed or used when the costs (in the dynamic cost–resource curve) for the electricity are lower than the electricity reference price (for

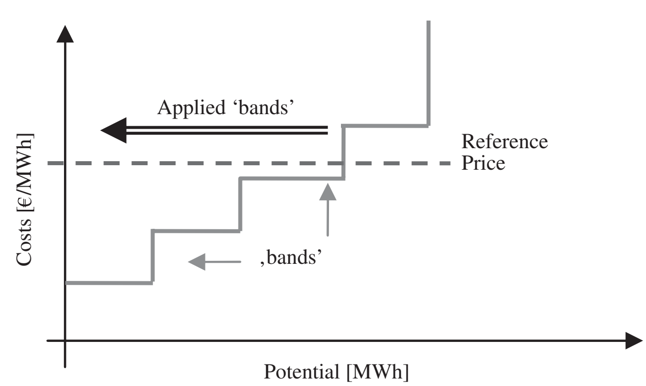

Fig. 1. Static cost resource curve.

further details for costs–resource curves, see Resch et al., 2004).

4. Case study for the island of Crete

Crete is located in the southern part of Greece. With a population of 601,131 inhabitants and a surface of 8336 km^2, Crete is the largest island of the country. RES electricity production in Crete covers almost 15% of the total electricity demand (Zografakis, 2001). In the eastern and central parts of the island, wind power plants raise the total installed capacity up to 108 MW while a number of new wind parks are under construction. In the western part of Crete, two small hydro stations are in operation with a total installed capacity of 0.76 MW. PV systems, although still quite expensive, are installed in different parts of the island covering a small share of the electricity demand (0.67 MW).

4.1. RES potentials and promotion schemes

This section provides a basis for the evaluation of the results obtained by INVERT and describes the current RES situation in Crete. Currently, total electricity demand on the island of Crete is 2140 GW h/yr and the electricity from RES is mainly generated by wind plants, small hydro stations and PV systems. However, Crete has also a great potential of biomass and solar thermal energy, as shown in Fig. 2.

RES technologies in Crete are supported by the government by means of investment subsidies and feed-in tariffs. Financial support schemes are summarised in Table 1 and have a guaranteed duration of 20 years.

4.1.1. Wind-on-shore plants

Wind energy covers 12.7% of the total electricity demand of the island. Although Crete has an additional wind electricity potential of more than 900 GW h/yr, until now only 336.7 GW h/yr are produced by wind turbines as depicted in Fig. 3. The existing promotion policy (Bakos, 2003) for wind energy is a 30% subsidy of the investment costs, according to the National Development Law of Greece, and FITs of 0.079 €/kW h according to Law 2773/99 supplemented by Law 2941 of 2001. FITs refer to the non-interconnected island of Crete. It is the price that the Power Public Cooperation (PPC) has to pay in order to buy electricity from independent producers (not autoproducers).

4.1.2. Small hydro stations

Small hydro stations produce up to 6.51 GW h/yr of electricity (Fig. 3) which accounts for 0.3% of the total electricity demand, while the additional electricity potential for small hydro reaches 25 GW h/yr. Investment subsidy of 40% and FITs of 0.079 €/kW h are also available for hydro energy.

Table 1
Support schemes for RES in Crete

	Investment subsidy (% of investment costs)	Feed-in tariffs (€/kW h)	Guaranteed duration of support (years)
Wind-on-shore plants, solar thermal units	30	0.079	20
Small hydro stations, biomass energy	40	0.079	20
Photovoltaic systems	40–50	0.079	20

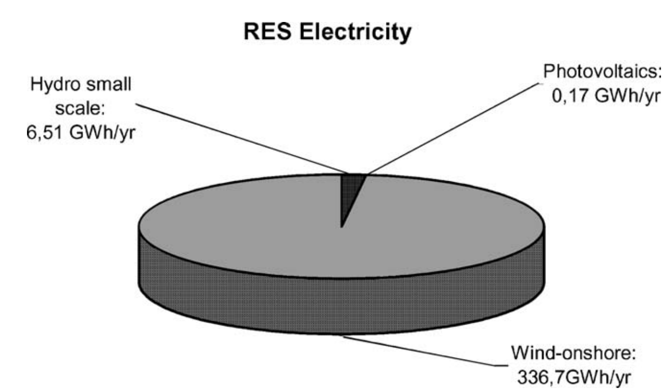

Fig. 3. Total electricity output from RES-E plants (GW h/yr) in 2004.

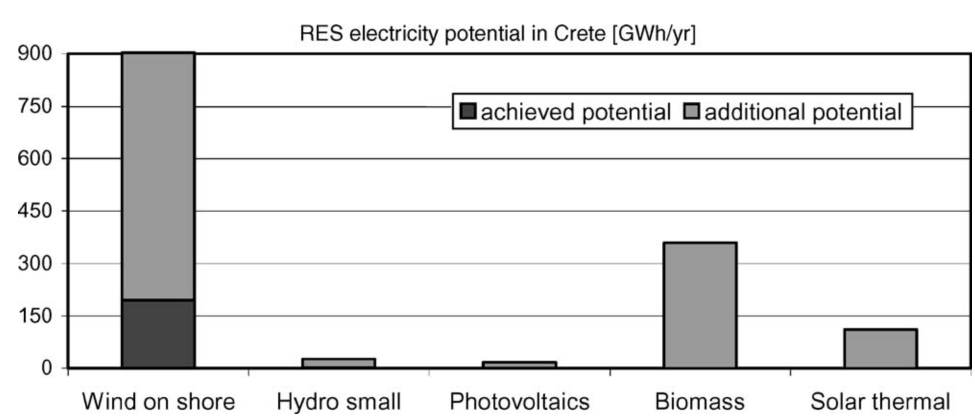

Fig. 2. RES electricity potential on the island of Crete.

4.1.3. Photovoltaic systems

The share of PV systems is still small, mainly due to high prices of PV panels. Solar energy accounts for 0.17 GW h/yr (Fig. 3) and covers only 0.1% of total electricity demand. The available potential on the island is approximately estimated to be 16.5 GW h/yr. In case of PV systems, investment subsidies can vary from 40% to 50%, but FITs are fixed to 0.079 €/kW h.

4.1.4. Biomass energy

Currently, agricultural residues (solid biomass) are only used on the island to produce heat. However, biomass electricity potential is very high and in the future, electricity generation from biomass products could reach 360 GW h/yr. Promotion schemes are offered an investment subsidy of 40% and a feed-in tariff of 0.079 €/kW h.

4.1.5. Solar thermal power plants

There is an innovative pilot solar thermal system for electricity production in Crete (Zografakis, 2001). Currently, although solar thermal is only used for DHW applications, the available electricity potential of the island is very promising, since 112 GW h/yr could be produced from solar thermal power plants.

4.2. Sensitivity analysis for the island of Crete

The island of Crete has a great potential for new RES plants. However, high investment costs often act as obstacles for new investors. Given the fact that the existing autonomous electrical system faces a problem caused by the high increase in electricity demand, further installation of RES plants could be a solution. Taking into consideration that the government should avoid spending an enormous amount of money, we consider a stepwise increase in the level of promotion schemes via various sensitivity analyses and check the results of the runs. In this way, we are able to identify the best solution for the island of Crete (see also Ragwitz et al., 2005).

4.2.1. Assumptions for the reference scenario

The reference scenario which includes all existing RES technologies of the island of Crete was simulated with INVERT. The runs were performed till 2020 and the results gained from the tool are shown in Fig. 4. Electricity potential and the level of promotion schemes are simulated as described in Fig. 3 and Table 1. We have assumed an increase in the electricity price from 33 to 36 €/MW h till 2020 and we have considered the fuel price of biomass about 20 €/MW h prim. Finally, we have also made the assumption that support schemes are kept constant until 2020 and that PV investment costs are reduced by about 1% per year.

The main results for the reference scenario, as shown in Fig. 4, are:

- Electricity generation from wind energy rises every year and reaches almost its possible maximum in 2020.
- The current investment subsidy for small hydro will also contribute to the continuous electricity production up to 2020.
- Despite the high available potential for PV systems, electricity generation will not exceed 0.17 GW h/yr up to 2020. The existing promotion scheme has no positive impact on the installation of new PV panels.
- Biomass-fuelled power plants for electricity production will be installed on the island after 2016.
- According to the results shown in Fig. 4, solar thermal power plants will start operating after 2009.

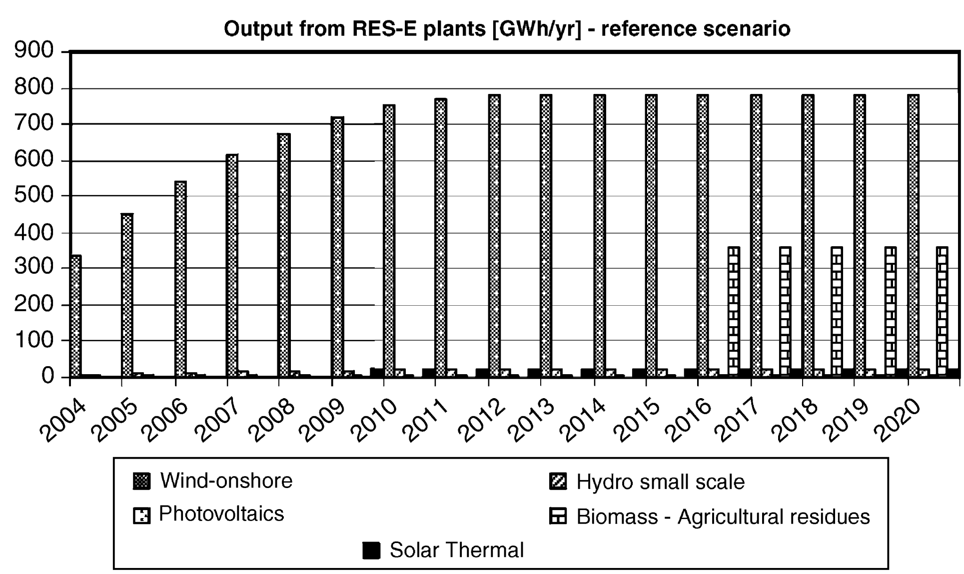

Fig. 4. Total electricity output from RES-E plants (GW h/yr)—reference scenario.

4.2.2. Promotion scheme efficiency

A promotion scheme efficiency (PSE) (Stadler et al., 2005) will be used as a significant parameter for the evaluation of different promotion schemes. The PSE is defined as follows[3]:

$$\text{Promotion scheme efficiency (PSE)} = \frac{\sum_{i=1}^{n} \Delta\,\text{CO}_2\,\text{emissions}_i}{\sum_{i=1}^{n} \Delta\,\text{Transfer costs}_i}, \quad (1)$$

where ΔCO_2 emissions$_i$ is the change in CO_2 emissions compared to the reference scenario (kton/yr), ΔTransfer costs$_i$ is the *relevant*[4] change in transfer costs compared to the reference scenario [Mio €/yr]; n is the number of simulation years.

The PSE estimates the efficiency of a certain strategy compared to a business as usual (BAU) scenario by comparing the CO_2 emissions and society costs for promoting a certain technology of the reference scenario with the CO_2 emissions and society costs of the sensitivity scenario.

Efficient promotion schemes (second best solution)[5] are indicated by high decreases in CO_2 emissions and low increases of transfer costs compared to the BAU scenario.

The expected situation is that new promotion policies on RES will lead to the reduction of CO_2 emissions. At the same time, transfer costs for promotion schemes will increase. Normally, money is spent to reduce emissions. The CO_2 substitution level is assumed to be the same for all RES-E technologies and is estimated with 0.5 ton CO_2/MW h.

4.2.3. Different measures of promotion schemes

With the use of the INVERT computer tool, various levels of promotion schemes were simulated and compared to the reference scenario, with respect to the PSE. The level of support used for the simulation is the minimum raise of investment subsidy or FITs, which has an impact on the deployment of a RES technology:

- Increasing the investment subsidy for wind energy and hydro small by 20–30% will not have a positive impact on the development of wind-on-shore plants. Spending more money for the promotion of wind-on-shore plants and small hydro stations in Crete is not an efficient policy and should not be considered. However, a reduction by 10 €/MW h in FITs for these technologies shows that the deployment of wind power plants and small hydro stations remains the same. In this case, we assume that the government could save money by considering a decrease of 10 €/MWh in FITs for wind and small hydro plants.
- In case of PV systems, the additional electricity potential (16.5 GW h/yr) of Crete cannot be explored due to its high investment costs. Due to the fact that PV panels are not produced in Greece, costs are high despite the government's support. We have tested simulation runs with 100% investment subsidy, but the achievable potential is limited to 0.17 GW h/yr every year.
- Raising the investment subsidy for biomass by 20% will lead to an earlier RES-E generation. CO_2 emissions reduction will be 180 kton/yr from 2004 to 2015, and furthermore, PSE is ca. 9.97 kg CO_2/€. A lower level of the investment subsidy (less than 20%) does not lead to a CO_2 reduction, whereas a higher level (more than 20%) will not change the deployment of biomass energy. In combination with investment subsidy, we have considered a raise in FIT by 5 €/MW h to 10 €/MW h. As indicated, in Fig. 5, the first option seems to be the best strategy with a higher PSE and a minimum amount of transfer costs.
- The minimum raise of investment subsidy for solar thermal power plants which have a high impact and contribution to RES electricity production is the reduction in CO_2 emissions by 11.2 kton/yr from 2004 to 2008 and PSE results to 5.41 kg CO_2/€. Different levels of FIT have been simulated for the sensitivity analysis. Results in Fig. 6 show that when adding the support of FIT, PSE does not rise; the first option achieves the same CO_2 reduction with the others but with lower transfer costs.
- Raising the FITs by 5, 10 and 15 €/MW h for RES without any change in investment subsidies. In the second case (FIT = 10 €/MW h), CO_2 emissions are reduced by about 230 kton/yr till 2017 and by about 40 kton/yr from 2018 to 2020, while PSE is 6.9 kg CO_2/€. Simulation runs indicate that a raise of 10 €/MW h will result in the highest CO_2 reduction (Fig. 7) while spending more money on FIT does not have a further impact on CO_2 emissions.

4.2.4. Results and discussion

Higher investment subsidies and/or feed in tariffs will only result in CO_2 reductions and high PSEs in case of relatively "new" RES technologies for the island of Crete, such as biomass. Various simulation runs have shown that the efficiency—according to CO_2 reductions—of the spent money depends strongly on the already achieved RES potential on the island of Crete. With respect to wind power plants and small hydro stations, PSE is very low due to the fact that electricity is already generated by these RES

[3]Note, in the INVERT simulation tool, two different PSE indicators are used. These two values (CPSE/LPSE) indicate the second best promotion schemes by negative values. However in this paper, we use the negative LPSE value and term it PSE. Negative CPSE/LPSE values indicate a CO_2 reduction accompanied with increased spent public money compared to the reference scenario. Therefore, the second best promotion schemes are identified by negative CPSE/LPSE (= +PSE) values.

[4]Let us assume a simulation period till 2020. In case of investment subsidies and use of a new measure in 2019, the entire costs get considered, but the CO_2 reductions get only considered for 2 years (2019 and 2020). This circumstance results in an underestimation of the PSE. Due to this circumstance, only the relevant transfer costs are counted for the PSE via estimation functions.

[5]The best solution is a decrease in CO_2 emissions accompanied with a decrease in spent public money.

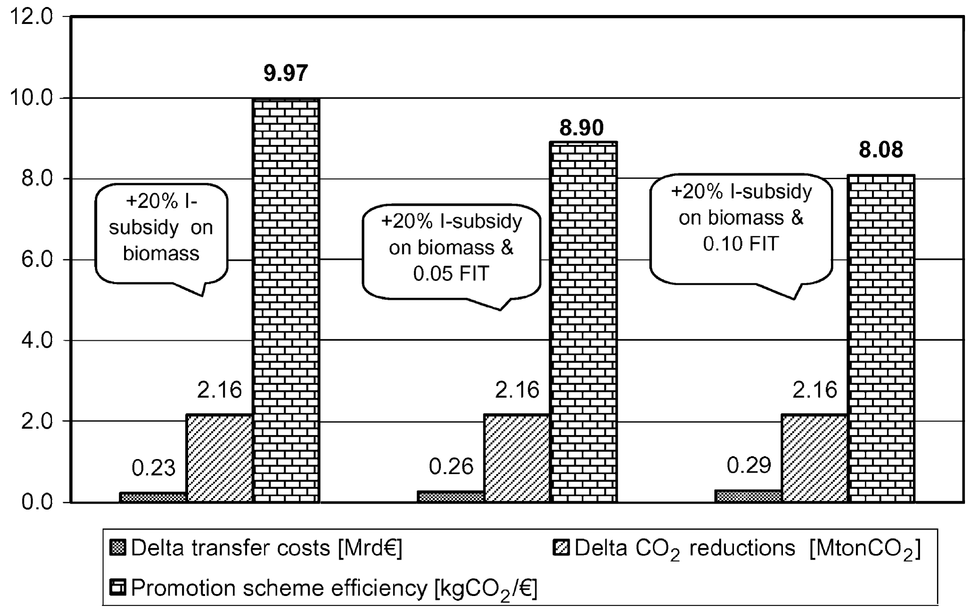

Fig. 5. Promotion scheme efficiency for new biomass strategies.

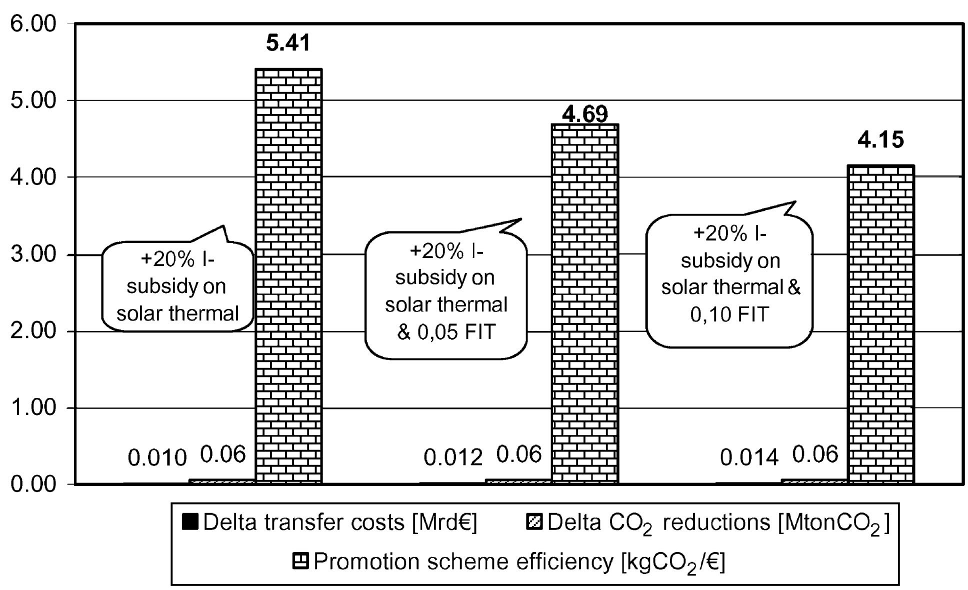

Fig. 6. Promotion scheme efficiency for new solar thermal strategies.

technologies on the island. Therefore, in comparison to the reference scenario, there are certain promotion schemes with lower or higher PSE.

The optimum solution of each figure (Figs. 5, 6 and 7) is summarised in Fig. 8. Raising the FIT (on RES electricity produced by biomass or solar thermal plants) by 10 €/MW h is the best promotion scheme with respect to the optimum CO_2 reductions (2.92 Mton). However, transfer costs are almost doubled (0.48 Mrd€) compared to the case of increasing the investment subsidy of biomass by 20% (0.23 Mrd€). The strategy suggested for FIT can achieve 2.92 Mton CO_2 reductions with transfer costs up to 0.48 Mrd€, while the biomass strategy results in 2.16 Mton reduction in CO_2 emissions with almost half the transfer costs (0.23 Mrd€). PSE is also higher for the "+20% biomass" promotion scheme (9.97 kg CO_2/€) in comparison to "+10 FIT" strategy (6.9 kg CO_2/€). Consequently, biomass subsidy is the best solution for the island of Crete.

5. Conclusions

In conclusion, we can gather that the optimum RES strategy for the island of Crete depends on the desired CO_2 reduction goal and the amount of money a government can afford. In case of Crete, all three promotion strategies (raising investment subsidy for biomass, increasing investment subsidy for solar thermal and raising FIT) have a higher PSE in comparison to the reference scenario, and

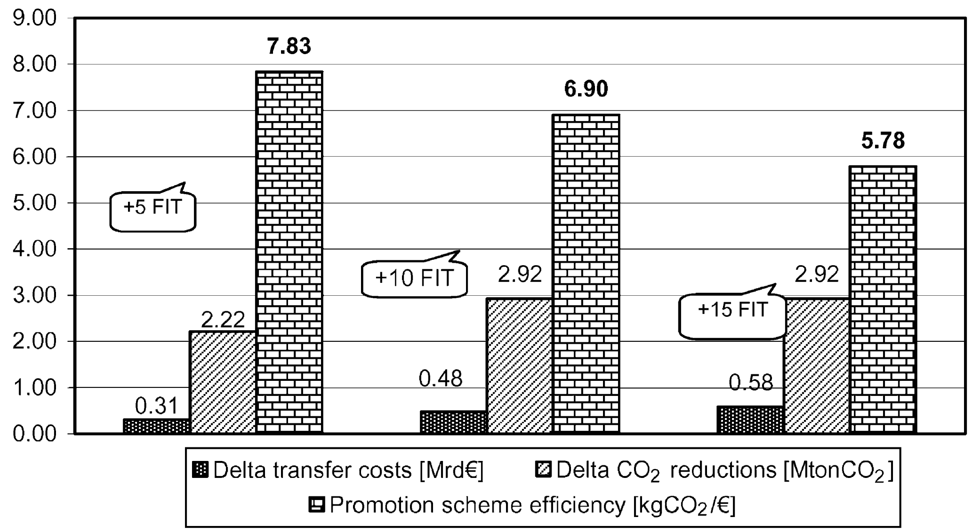

Fig. 7. Promotion scheme efficiency for new FIT strategies.

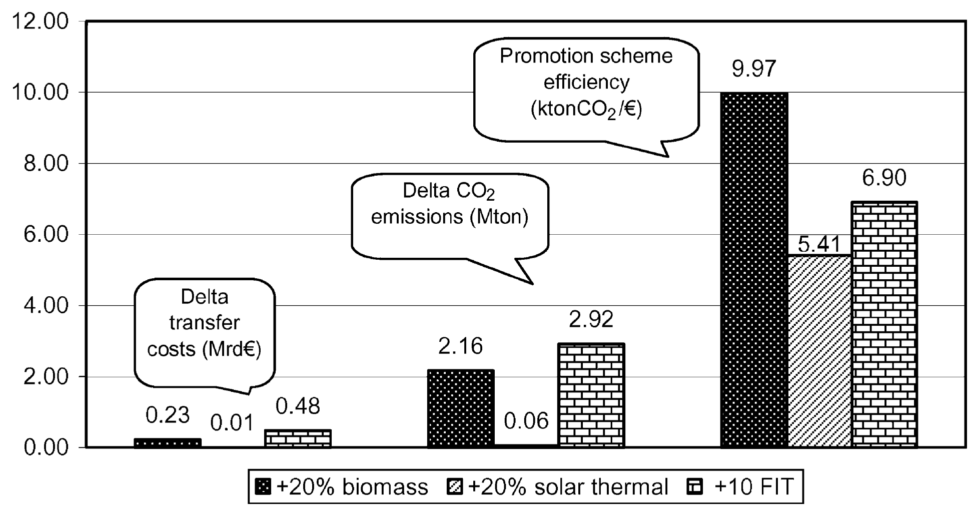

Fig. 8. Comparison of the optimum RES strategies.

are consequently suggested for implementation. Raising the subsidy in biomass will contribute to a significant CO_2 reduction and will cost half the money in comparison to raising the FITs. Higher investment subsidies for solar thermal power plants result in low PSE and lower (in comparison to other strategies) CO_2 reduction. Consequently, if the government has to choose one strategy among the strategies described in this paper, raising the investment subsidy for biomass would be the optimum measure in terms of PSE.

Finally, energy policy serves as a framework within which objectives and targets are set at the national and regional level to ensure sustainable electricity production. Legislative measures and environmentally aware policy makers have a key role in the higher penetration of RES in the energy market. The results of this paper can be used to promote, in an efficient and environmentally manner, the use of renewables for electricity production.

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- AGH University of Science and Technology, Poland,

[6]For more information, please take a look at INVERT project, 2003–2005.

- Association for the Conservation of Energy, UK,
- Centro de Estudos em Economia da Energia, dos Transportes e do Ambiente, Portugal,
- Fraunhofer Institute for Systems and Innovation Research, Germany,
- Risoe National Laboratory, Denmark, and
- Polish Foundation for Energy Efficiency, Poland.

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