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A model for renewable energy symbiosis networks in eco-industrial parks

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Abstract: Renewable energy technologies integration within industrial districts can boost carbon emissions reduction in the industry sector. The eco-industrial parks model promotes the sustainable use of energy and the application of energy synergies and energy exchanges that can include renewable sources of energy. This paper presents an optimization methodology based on a multi-stakeholder perspective to evaluate energy symbiosis including the integration of renewable energy sources within the parks. The study results in three scenarios providing to managers of single firms and parks relevant information for supporting decision making regarding the economic sustainability and the environmental impacts of the energy synergies. The results show that the optimization of the collective point of view ensures more efficient management of the energy supplied by renewables as well as by firms that can provide an energy surplus.

Keywords: Renewable energy systems, Decision making, Models, Environment, Energy dependence, Energy management system, Industrial production systems.

1. INTRODUCTION

Eco-industrial parks (EIPs) are industrial clusters oriented towards the realisation of sustainable practices and objectives, where companies can develop cooperation initiatives and share resources (Le Tellier *et al.*, 2019). Energy symbiosis within EIPs can enable the uptake of renewable energy sources (RES) at the industrial level (Butturi *et al.*, 2019). Along with energy efficiency policies, renewable energy technologies investment is considered essential to reduce the carbon footprint of industries (IEA/OECD and Cédric Philibert, 2017). The main condition to justify implementing a collective strategy is to demonstrate that the sum of benefits achieved by working collectively is higher than working as a single industrial enterprise (Boix *et al.*, 2015).

The main goal of optimizing industrial and energy symbiosis is to design an optimal energy network configuration, typically considering economic and environmental indicators. Different stakeholders with potentially contrasting objectives must be considered, including the individual firms located in the park, nearby local authorities, and citizens (Kuznetsova *et al.*, 2016).

This article presents an optimization methodology to support energy managers, single firms, groups of firms within EIPs, and decision-makers to evaluate energy synergies and projects involving RES within EIPs. It analyses the economic convenience and environmental impact of energy symbiosis when RES satisfy a percentage of the energy demanded by EIPs. Through analysing three different perspectives, the single firm point of view, the environmental optimization, and the EIP collective perspective, three scenarios are studied.

The remainder of this article is structured as follows. Section 2 presents the main aspects related to energy symbiosis involving RES. Section 3 describes the methodology and models. Section 4 provides the reference case to test the model. Section 5 includes the results and a discussion of the findings. Lastly, section 6 draws the conclusions, outlining some future research directions.

2. ENERGY SYMBIOSIS INVOLVING RES

The EIP model enables the implementation of various energy strategies, depending on the energy demand profile of firms and their willingness to cooperate. It can enable energy exchanges, joint projects for energy efficiency, and collective energy production, aiming at reducing the overall energy use and pollutant emissions (Fichtner *et al.*, 2004). This article focuses on the availability of energy from renewable sources. While a single company may not be able to invest in installing renewable power units due to lack of funds, insufficient space (roof or ground surface) or internal expertise, the EIP model facilitates to overcome these barriers. Individual companies can be either connected to energy conversion units or to an internal energy network handling any energy overproduction (Butturi *et al.*, 2019).

In this study, we introduce a mathematical model to analyse the integration of RES in the energy system of an EIP from a structural point of view. While energy symbiosis modelling has been widely analysed (Kuznetsova, Zio and Farel, 2016), only a few articles consider RES integration (Butturi *et al.*, 2019). The main goal of the study is to capture the major costs and environmental impacts of an energy symbiosis scheme including RES.

Fig. 1 represents the considered energy symbiosis within the EIP. The EIP is connected to the distribution grid (the standard power suppliers are fuelled by fossil sources) that

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can satisfy all the electrical energy demand. Among the EIP's participants, some firms buy the whole electricity needed to satisfy their demand (buyers), while others can deliver an amount of renewable excess energy (suppliers). In addition, the EIP organization may enable the joint installation and use of cleaner energy units (eco power plants).

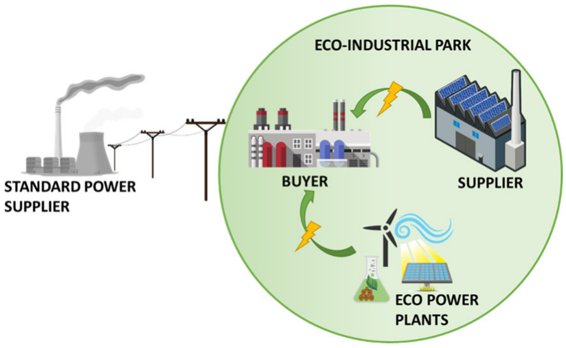

Fig. 1. General scheme of energy symbiosis within EIP.

3. THE MATHEMATICAL MODELS

Mixed-integer linear programming (MILP) is one of the main methods used to optimize energy exchange networks (Kastner, Lau and Kraft, 2015). The mathematical optimization through MILP allows optimal energy symbiosis design, considering both economic and environmental issues via multi-objective formulation.

Following the stakeholders' approach and starting from the models proposed by Afshari *et al.* (2018), three models have been developed to include renewable technologies in the energy symbiosis network. The first model aims at minimizing the total costs of buying energy for each firm and represents the single buyer point of view. The second model analyses the environmental impact. Finally, the third model provides the collective point of view, considering both the energy buyers and suppliers and simultaneously the model cost and the environmental impact (Fig. 2).

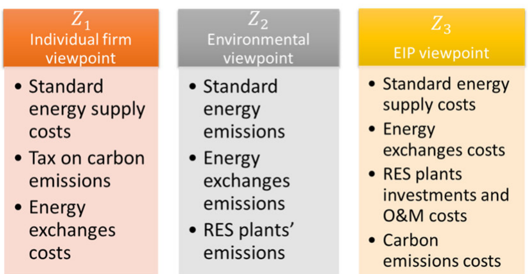

Fig. 2. Comparison of the main purposes of the models.

3.1 Variables and parameters

Sets, parameters, and variables are listed as follows.

Sets:

$I = I.Sup \cup I.Eco$ set including both the renewable power generation units that could be installed (I.Eco) and the firms that can supply a surplus of power (I.Sup).

J set of firms demanding energy
T set of the time period (in years)

Parameters:

D_j^t [kWh] Energy demand of firm j in year t
FD_j^t [€] Fixed cost
VD_j^t [€/kWh] Variable cost
IP_j^t [kgCO$_2$/kWh] Environmental impact due to standard power production
RC_i^t [€/kWh] Variable cost of recovering energy within the firm i in year t
FC_i^t [€] Fixed cost of recovering energy within the firm i in year t
PE_i^t [€/kWh] Selling price of energy from supplier firm i
IC_i [€] Investment cost for renewable power unit i
P_i^t [kW] Nominal power for unit i in t
S_i^t [kWh] Energy converted by unit i in t
CM_i^t [€] Fixed cost for maintenance of renewable power unit i
CO_i^t [€/kWh] Variable operational cost for renewable power unit i
EP_i^t [kgCO$_2$/kWh] Environmental impact due to renewable power production in unit $i \in I.Sup \cup I.Eco$
L_{ij} [km] Distance between i and j
CC_{ij} [€] Investment cost for the link between i and j
γ [km] Maximum distance between i and j
EC^t [€/kgCO$_2$] Emission allowance cost
LW [%] Maximum potential loss for wind energy
LPV [%] Maximum potential loss for PV energy
LB [%] Maximum allowed loss for biomass energy
LBW [kWh] Loss of the biggest wind power unit
$LBPV$ [kWh] Loss of the biggest PV power unit
$LBBM$ [kWh] Loss of the biggest biomass power unit
PI^t [kWh] System peak load in year t
$share_r$ [%] Energy demand satisfied by renewables
RM [%] Reserve margin of the system
s Annual discount rate

Variables (BV = binary variable):

x_{ij}^t BV if symbiosis exists between i and j in t
y_{ij}^t Amount of energy demand for j satisfied by i in t
h_j^t BV if firm j achieves the energy independence in t
w_{ij} BV representing the investment cost if symbiosis exists between i and j
z_i BV representing the investment cost if the eco-plant i is installed

3.2 The objective functions

The first objective function (1) aims at minimizing the total costs of buying energy for each individual firm, considering the entire period T. The blocks represent the sum of fixed and variable costs of the non-renewable (standard) energy bought and the cost of the renewable energy from supplier firms. The last part takes into account the CO$_2$ emissions allowance due to the bought standard energy only. The objective function does not consider the cost of a new plant installation.

$$\min Z_1 = \sum_{t \in T} \left\{ \sum_{j \in J} \left[FD_j^t \left(1 - h_j^t\right) + VD_j^t D_j^t \left(1 - \sum_{i \in I} y_{ij}^t \right) + \right. \right.$$

$$+\sum_{i\in I.Sup} PE_i^t D_j^t y_{ij}^t +$$

$$+EC^t IP_j^t D_j^t\left(1-\sum_{i\in I} y_{ij}^t\right)\Bigg]\Bigg\}(1+s)^{-t} \qquad (1)$$

The second objective function (2) considers the environmental impact and aims at minimizing the whole carbon emissions due to the energy conversion technologies and connections. The blocks represent the emissions due to the external power generation (from plant fuelled by fossil sources) and the emissions due to power generation respectively by supplier firms and renewable plants.

$$\min Z_2 = \sum_{t\in T}\sum_{j\in J}\Bigg[IP_j^t D_j^t\left(1-\sum_{i\in I} y_{ij}^t\right) + D_j^t \sum_{i\in I.Sup} EP_i^t y_{ij}^t +$$

$$+\sum_{i\in I.Eco} EP_i^t S_i^t x_{ij}^t\Bigg] \qquad (2)$$

The third objective function (3) considers the optimization of both the costs and the environmental impact from a collective point of view, analysing at the same time the buyers' and the suppliers' benefits. The blocks represent the sum of the fixed and variable cost of standard energy delivered by standard plants; the cost of the renewable energy delivered by supplier firms including the recovery cost; the fixed and variable cost for the installation of new ecological plants; the CO_2 emissions allowance due to the standard energy and the exchanged energy. The last part considers the investment cost of new plants and connections.

$$\min Z_3 = \sum_{t\in T}\Bigg\{\sum_{j\in J}\Bigg[FD_j^t\left(1-h_j^t\right) + VD_j^t D_j^t\left(1-\sum_{i\in I} y_{ij}^t\right)\Bigg] +$$

$$+\sum_{j\in J}\sum_{i\in I.Sup}\left(FC_i^t x_{ij}^t + RC_i^t D_j^t y_{ij}^t\right) + \sum_{i\in I.Eco}\left(CM_i^t z_i + \sum_{j\in J} CO_i^t D_j^t y_{ij}^t\right) +$$

$$+\sum_{j\in J}\Bigg[EC^t IP_j^t D_j^t\left(1-y_{ij}^t\right) - EC^t \sum_{i\in I.Sup} EP_i^t D_j^t y_{ij}^t +$$

$$+EC^t \sum_{i\in I.Eco} EP_i^t\left(S_i^t - D_j^t y_{ij}^t\right)\Bigg]\Bigg\}(1+s)^{-t} +$$

$$+\sum_{i\in I.Eco} IC_i z_i + \sum_{j\in J}\sum_{i\in I} CC_{ij} w_{ij} \qquad (3)$$

3.3 Constraints

Constraints (4 to 8) define the type of the variable.

$$x_{ij}^t \in \{0,1\} \qquad \forall\ t,i,j \qquad (4)$$

$$0 \le y_{ij}^t \le 1 \qquad \forall\ t,i,j \qquad (5)$$

$$z_i \in \{0,1\} \qquad \forall\ i \in I.Eco \qquad (6)$$

$$w_{ij} \in \{0,1\} \qquad \forall\ i,j \qquad (7)$$

$$h_j^t \in \{0,1\} \qquad \forall\ t,j \qquad (8)$$

Constraint (9) refers to satisfy up to the whole buyers' energy demand. Constraint (10) guarantees that, if symbioses are working, an amount of energy demand is satisfied; similarly, (11) guarantees that an eco-plant is operating only if there is energy demand, and (12) guarantees that the cost of existing symbioses is considered. Constraint (13) verify the energy independence of a buyer firm; and (14) defines the geographical limits of the park dictating a maximum distance between buyer and supplier.

$$\sum_{i\in I} y_{ij}^t \le 1 \qquad \forall\ t,j \qquad (9)$$

$$y_{ij}^t \le x_{ij}^t \qquad \forall\ t,i,j \qquad (10)$$

$$\sum_{t\in T}\sum_{j\in J} x_{ij}^t \ge z_i \qquad \forall\ i \in I.Eco \qquad (11)$$

$$\sum_{t\in T} x_{ij}^t \ge w_{ij} \qquad \forall\ i,j \qquad (12)$$

$$h_j^t \le \sum_{I} y_{ij}^t \qquad \forall\ t,j \qquad (13)$$

$$\left(L_{ij} w_{ij} - \gamma\right) \le 0 \qquad \forall\ i,j \qquad (14)$$

The next group of constraints manages the relation between demand and supply. Constraint (15) guarantees that suppliers can provide excess energy to support the exchanges and (16) controls that the energy supplied does not exceed the surplus availability.

$$D_j^t y_{ij}^t \le S_i^t x_{ij}^t \qquad \forall\ t,i,j \qquad (15)$$

$$\sum_{j\in J} D_j^t y_{ij}^t \le S_i^t \qquad \forall\ t,i \qquad (16)$$

Constraint (17) and (18) dictate the economic sustainability of the symbioses for the buyers and suppliers respectively, while (19) dictates the economic sustainability from the collective point of view.

$$FD_j^t + VD_j^t D_j^t \sum_{i\in I.Sup} y_{ij}^t + IP_j^t D_j^t EC^t \sum_{i\in I.Sup} y_{ij}^t \ge$$

$$\ge \sum_{i\in I.Sup}\left[\left(PE_i^t - EC^t IP_j^t\right) D_j^t y_{ij}^t\right] \qquad \forall\ t,j \qquad (17)$$

$$\sum_{j\in J} PE_i^t D_j^t y_{ij}^t \ge \sum_{j\in J} RC_i^t D_j^t y_{ij}^t +$$

$$+\sum_{j\in J} FC_i^t x_{ij}^t - \sum_{j\in J} EC^t EP_i^t D_j^t y_{ij}^t \qquad \forall\ t, i \in I \qquad (18)$$

$$\sum_{t\in T}\left[\sum_{j\in J}\left(FD_j^t + VD_j^t D_j^t \sum_{i\in I.Eco} y_{ij}^t + EC^t IP_j^t D_j^t \sum_{i\in I.Eco} y_{ij}^t\right)\right](1+s)^{-t} \geq$$
$$\geq \sum_{t\in T}\left\{\sum_{i\in I.Eco}\left[CM_i^t z_i + CO_i^t \sum_{j\in J} D_j^t y_{ij}^t\right]\right\}(1+s)^{-t} +$$
$$+\sum_{j\in J}\sum_{i\in I} CC_{ij} w_{ij} + \sum_{i\in I.Eco} IC_i z_i \qquad (19)$$

Constraint (20) ensures the availability of the demanded energy even if fluctuations in the supply occur.

$$RM\sum_{t\in T}\sum_{i\in I} S_i^t x_{ij}^t \leq \sum_{t\in T}\sum_{i\in I} S_i^t x_{ij}^t - LW\sum_{t\in T}\sum_{i\in I.Wind} S_i^t x_{ij}^t +$$
$$-LPV\sum_{t\in T}\sum_{i\in I.PV} S_i^t x_{ij}^t - LB\sum_{t\in T}\sum_{i\in I.Bio} S_i^t x_{ij}^t +$$
$$-LBW - LBPV - LBBM - Pl^t \qquad \forall\ t \qquad (20)$$

Constraint (21) controls the possibility of introducing a minimum share of renewable energy.

$$\sum_{j\in J}\sum_{i\in I} D_j^t y_{ij}^t \geq Share_r \sum_{j\in J} D_j^t \qquad \forall\ t \qquad (21)$$

Constraints (20) and (21) have been developed starting from the model of Pereira *et al*. (2016).

4. THE REFERENCE CASE

To ensure the complete availability of data for testing the model, a representative industrial park, encompassing 9 firms, has been studied; 3 potentially energy suppliers (S1 to S3) and 6 energy buyers (B1 to B6). We consider also the possibility of installing 3 biomass plants, 3 wind plants, and 3 photovoltaic (PV) plants. The Euclidean distances between facilities are given.

4.1 Reference case data

The time range for the optimization (T) covers 10 years, while, according to Afshari *et al*., (2018), the maximum distance between two connected facilities is 20 km to avoid high cost for the connection infrastructures. The maximum potential loss for wind, photovoltaics, and biomass energy (*LW, LPV, LB*) has been calculated from published data on electric energy productivity (Terna Spa, 2018). The emission allowances cost EC^t is deducted from the EU emissions trading system, and the environmental impact due to standard power production IP_j^t considers the emissions factor as calculated by IPCC (Bruckner *et al.*, 2014).

The percentage of the energy demand satisfied by renewables has been agreed according to the "2030 Climate & Energy Framework" of the European Union (European Commission, 2014). Three energy consumption profiles have been chosen for the energy buyers, considering high (range 1000 MWh/year), medium (range 100 MWh/year) and small (range 10 MWh/year) industry energy consumers according to Cialani and Mortazavi (2018).

The energy suppliers can provide an energy surplus in the range of thousands of kWh/year, calculated as 1% of the annual consumption of a medium firm.

The techno-economics data concerning the renewable technologies plants (eco-plants) have been extrapolated from Kost *et al.* (2018) and (IRENA, 2018). At this step, the eco-plants' dimensioning considers only the capacity of the energy units, since the model focus on the demand-supply mechanism.

The energy production S_i^t, over the period t, of $i_{\text{-th}}$ eco-plant can be written as a function of the capacity factor ϕ_i^t (22):

$$S_i^t = P_i \cdot \phi_i^t \cdot (365days)\cdot\left(24\frac{h}{days}\right) \qquad \forall t, i\in I.Eco \quad (22)$$

The global mean values for the capacity factors, according to (IRENA, 2018), are:

$\phi_{Wind} = 0{,}27 \div 0{,}33$ %
$\phi_{PV} = 0{,}15 \div 0{,}20$ %
$\phi_{Biomass} = 0{,}67 \div 0{,}74$ %
The carbon emissions for the different technologies have been extracted from (Schlömer S. *et al.*, 2014).

All the data of the reference case (the Euclidean distances between facilities, the complete set of parameters, the demand data and suppliers' related assumptions, the capacity and investment costs for the eco-plants, and the eco-plants' energy production simulation, costs and capacity factor data) are available upon request.

5. RESULTS AND DISCUSSION

The developed models have been coded and elaborated using MATLAB's *Optimization Toolbox* and a *problem-based* approach, to handle the big amount of data in matrix form.

5.1 The three optimised scenarios

Each model provides the optimization from its related perspective, building up three complex scenarios outlining all the energy flows among facilities (buyers, suppliers, and eco-plants) per year, on the total temporal range of 10 years.

In scenario 1, obtained by minimizing cost for the buyer firms, each buyer company, weighed equally in the optimization, is entirely fed by eco-plants. This scenario should be applied if a service company would take on investment, operation, and maintenance costs of the plants. In this case, the buyers would prefer buying the energy provided by the eco-plants rather than exchanging with suppliers because, after returning all the investments, the energy from renewable sources would cost less than a partner's surplus.

Both in scenarios 1 and 3 (concerning the collective perspective), the energy demand is fully satisfied with the facilities inside the park. In scenario 3, which considers any cost and savings of both buyers and suppliers, the inter-firm exchanges result to be the most economical choice.

In scenario 2, that minimises carbon emissions, the extension of the connections overcomes 260 km, since the minimization of environmental impacts does not include the minimization of infrastructure cost. Overall, in scenario 1, one wind power plant and all the PV and biomass units should be opened; in scenario 2, two PV plants and one wind plant are opened; in scenario 3 only two biomass plants are opened. Scenario 3 manages better the energy of the companies and plants. Supplier companies provide all their excess energy and the opened eco-plants supply more than 70% of their power production.

Fig. 3 presents a representative picture of the results, showing advantageous energy connections for the buyer B3 in the three different scenarios. Similar pictures have been obtained for all the six buyer firms.

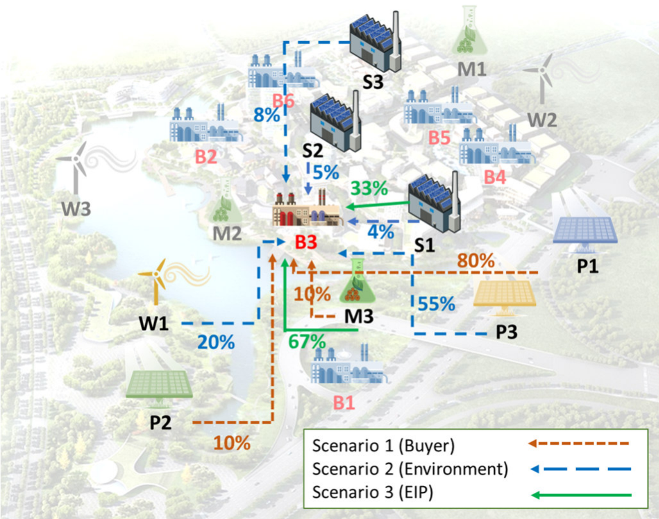

Fig. 3. B3 advantageous energy connections.

The average amount of the energy demand satisfied over the entire period T is shown in percentage. In scenario 1 (red dotted line), the energy demand of the buyer B3 results entirely satisfied by two PV plants and a biomass plant (orange dotted line). Scenario 2, which minimizes the environmental impacts (dashed blue lines), shows the activation of energy flows between B3 and two different renewable technologies units (PV and wind). According to IPCC (Bruckner *et al.*, 2014), we considered the life-cycle emissions for the eco-plants, so in the calculation, the carbon emissions of PV and wind systems are not null. In addition, energy symbioses between the buyer B3 and the suppliers are activated. S1, S2, and S3 supply altogether the 17% of the buyer energy demand.

Scenario 3 is the collective scenario, balancing the needs of all stakeholders. As expected, it enables the activation of energy symbiosis between the buyer B3 and the supplier S1, which supplies 33% of the buyer's energy demand. The 67% of B3 energy demand is supplied by the biomass plant M3. Similar pictures can be traced to all the buyers.

To analyse, compare the scenarios, and support decision-making, we analyse the results introducing a set of indicators consistent with the objectives of the models.

5.2 Analysis metrics

The indicators consider the whole temporal range to get the positive aspects of the long-term plan. Indicators provide useful information on how efficiently the resources are used calculating the percentage of surplus energy unused or employed in the exchanges, the percentage of energy converted from renewable sources and the carbon footprint reduction.

Two energy efficiency indicators value the capacity of the system to exploit the available electrical energy. The greater the incidence of intra-park exchanges, the better the system logistic will become solid and resilient. These indicators show the amount of energy demand satisfied by energy exchanges or renewable plants within the park. The indicators are the energy symbiosis between buyers and suppliers (23) and the renewable energy converted by eco-plants use (24).

$$US = \sum_{t\in T}\sum_{j\in J}\sum_{i\in I.Sup}\frac{D_j^t y_{ij}^t}{S_i^t x_{ij}^t} \quad (23)$$

$$UE = \sum_{t\in T}\sum_{j\in J}\sum_{i\in I.Eco}\frac{D_j^t y_{ij}^t}{S_i^t x_{ij}^t} \quad (24)$$

The carbon emissions reduction in the three scenarios can be evaluated by (25):

$$ER = 1 - \sum_{t\in T}\sum_{j\in J}\frac{\sum_{i\in I.Sup} EP_i^t D_j^t y_{ij}^t + \sum_{i\in I.Eco} EP_i^t D_j^t y_{ij}^t}{\sum_{i\in I} IP_j^t D_j^t y_{ij}^t} \quad (25)$$

In relation to the environmental benefits, there will be a reduction in CO_2 emissions related cost expressed by (26):

$$TR = 1 - \sum_{t\in T}\sum_{j\in J}\frac{EC^t D_j^t \sum_{i\in I.Sup} EP_i^t y_{ij}^t + EC^t D_j^t \sum_{i\in I.Eco} EP_i^t y_{ij}^t}{EC^t IP_j^t D_j^t + EC^t \sum_{i\in I.Sup} EP_i^t S_j^t x_{ij}^t} \quad (26)$$

As economic indicator, we chose to analyse the economic convenience of exchanges for suppliers. Through the optimal solution of the three problems, it is possible to calculate the variation of cost before and after the realization of the energy symbiosis projects. The reduction of costs for suppliers (in percentage) is given by (27):

$$SG = 1 - \sum_{t\in T}\sum_{i\in I.Sup}\frac{\sum_{j\in J}\left[\left(EC^t EP_j^t + PE_j^t - RC_i^t\right)D_j^t y_{ij}^t - FC_i^t x_{ij}^t\right]}{EC^t EP_i^t S_i^t x_{ij}^t} \quad (27)$$

5.3 Scenarios analysis and comparison

The calculation of the introduced indicators allows to further analyse advantages and disadvantages of the three scenarios. The framework of scenario 3 fully exploits energy exchanges, while scenario 1 maximizes the eco-plants use, without considering the investment cost. All the scenarios achieve significant emission reduction. Regarding environmental benefits, there will be a reduction in the CO2 emissions related cost, greater in scenarios 1 and 3. The cost reduction is greater in scenario 2 since maximizing exchanges involves more infrastructure costs (though shared with buyers).

Table 1 presents the calculated indicators, as percentage.

The framework of scenario 3 fully exploits energy exchanges, while scenario 1 maximizes the eco-plants use, without considering the investment cost. All the scenarios achieve significant emission reduction. Regarding environmental benefits, there will be a reduction in the CO_2 emissions related cost, greater in scenarios 1 and 3. The cost reduction is greater in scenario 2 since maximizing exchanges involves more infrastructure costs (though shared with buyers).

Table 1. Calculated indicators for the model

%	Scenario 1	Scenario 2	Scenario 3
US	0	89	100
UE	43	24	27
ER	83	96	72
TR	93	61	99
SG	0	14	3

6. CONCLUSIONS

This article develops an optimization model for the evaluation of energy symbiosis within EIPs involving RES. It represents a step forward in the under-investigated field regarding the integration of RES in EIP (Butturi *et al.*, 2019). Though based on an abstract reference case, the preliminary results show a high potential in providing significant outcomes for energy managers.

Future research will include real cases to expand and validate the model. Additional techno-economic and sustainability-related issues will be taken into account. An energy storage option should be integrated to manage energy supply fluctuations. Regarding economic sustainability, since the energy symbioses are long-term projects, in the application of the model to case studies the payback period for utility installation will be calculated. Sensibility analysis and computational complexity O(.) should also be included in further applications.

Lastly, the study focuses on carbon emissions reduction, but a transition towards a more sustainable energy supply system in industrial districts should deal with a number of environmental impacts such as noise and odors, land use, impact on biodiversity or landscape that can affect renewable energy systems (Butturi *et al.*, 2018). Moreover, a more comprehensive sustainability view should include social impacts (Valenzuela-Venegas *et al.*, 2016).

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