

Sustainable rural communities – Steps and sustainability scenarios

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Abstract: *The transition towards sustainable communities represents a complex process that requires efficient, feasible, market and socially accepted solutions, adapted to the local specifics and respecting the major pre-requisites of sustainable development. There is no general transition pattern, therefore research is expected to formulate solutions focusing on the major issues raised by the energy production, consumption, storage and distribution. A methodology is presented and detailed considering the highly specific features of rural communities, heavily based on agriculture and with small local industry mainly based on agro-products. The paper outlines that rural communities can start the transition towards sustainability as follows: (1) increasing the energy efficiency at the buildings level and at the level of the joint community consumers; (2) analysis of the local renewable energy resources, considering the variability of their potential, including the wastes that are significant in a rural-based economy; (3) identifying the current and predicted energy demand (e.g. for the next 20...25 years, the lifetime of most solar energy converters); (4) based on these, the community can choose the degree of changes, i.e. the percentage of energy that can be obtained using renewables, considering affordability, feasibility, the current and the predictable legal frame, etc.*

Key Words: Sustainable community; Rural community; Renewable energy system; Renewable energy mix.

INTRODUCTION

Global warming and the associated worldwide threats require a re-focus towards sustainable development, both at scientific and policy levels; this is why the long and too slow political negotiations are now-a-days simultaneously running with the effort for identifying concrete, efficient and affordable solutions towards sustainability, involving social, environmental and technical aspects, [11], the last ones having energy as core subject.

Following the Kyoto Protocol and the sub-sequent legislation on CO₂ emissions decrease, an extended effort was devoted to the development and implementation of renewable based technologies (RET) which resulted in innovative and optimized renewable energy systems (RES); however, no matter how efficiently these could support global warming mitigation, the renewables implementation was and still is eventually limited by the rather large initial investment costs, therefore any successful story is linked to national support policies (as the case of Germany, [16]). Even so, the RET/RES implementation is mainly point-wise done, as an answer to the best national incentives schemes; although good (as any sustainability action), there is a need for faster progress in climatic changes limitation and in reducing the accelerated depletion of many critical resources (fossil fuels but also other rather common mineral resources), by extending the use of renewables and of wastes (as second raw materials). This asks for more integrated/synergetic actions and the concept of Sustainable Community well mirrors this approach.

There are many definitions of Sustainable Communities and almost all of them are outlining the pre-requisites for integrated economic – environment – social actions; however, most of the examples of good practice are mainly focusing on preliminary and scattered steps towards sustainability, involving community acceptance, commitment, education and less on aspects for implementing sustainability actions and particularly RET. This is why there are just few fully sustainable communities which were developed as “prove of the concept”, as the well-known example - the Vauban district in Freiburg, Germany [9].

Rural communities have specific features that recommends them as (more) successful candidates for sustainability as compared to the urban districts, towns or cities. To identify, harmonize and best exploit these features represents a challenge recognized at international level through a specific decision (E/CN.17/2009/19) of the UN Commission for Rural Development, [22]. The five-points decision outlines the need for investment “in

essential infrastructure and services for rural communities”, including RET and supporting integrated resources and utilities planning.

Starting from the analysis of several important specific features of rural communities, this paper presents the steps to be followed in the design of a sustainable community, focusing on the technical aspects that support the implementation of RET; the paper outlines the need for a personalized sustainable development scenario, that gives maximum use to the local renewable energy sources, while respecting the tradition and aiming at economic development.

SUSTAINABLE COMMUNITIES

There are not two communities alike. Some of the quantifiable differences that are important in designing a sustainable energy scenario are related to:

- *the location*, with influence on the climatic profile, thus on the available resources and on the energy demand in the built environment;
- *the community size*, i.e. the population/end-users number, the number of households, the number of buildings, etc., that will be directly linked to the energy and water consumption in the built environment;
- *the connection to local/national utilities grids* that will significantly differentiate among the sustainable energy scenarios;
- *the level of economic development* that directly influences the energy demand coming from various agricultural, industrial, tourism and social activities; additionally, the economic development will also influence the financial power of the community, thus the RET solutions that qualify as affordable;
- *the level of social development* that is linked to the demand (e.g. for comfort) and to the likely communitarian acceptance of new energy solutions.

Aspects that are more difficult to quantify have also to be considered because of their large influence on planning, like cultural and education levels, traditions, heritage, etc.

Current situation and needs in rural communities

These differences have specific features in rural communities:

- ***the location***: rural communities are not usually developed as conglomerates in narrow areas, therefore having more available space for implementing RES. This gives a larger unexploited renewable energies potential as compared to urban communities and makes rural areas better suited for sustainable energy scenarios, [7]. However, the energy-food competition for the land has to be well managed and the use of degraded or unproductive soils should get priority in implementing RES.
- ***the community size***: rural communities are rather small; however the size significantly ranges from several tenth (for highly remote, sparse communities), to an usual number of hundreds of inhabitants, up to 10000 for rural communities close to large urban agglomerations. Considering the needs and demands of the latest, they can better be described as urban outskirts, thus are more resembling the urban communities and do not represent the focus of this study. Another specific feature of a typical rural community is the prevalence of houses with yards and gardens (vs. blocks of flats, condominiums, etc.), with various degrees of insulation thus with very different thermal energy consumption.
- ***the connection to the local/national utility grids*** should be analyzed for the main utilities: electricity, thermal energy and water.
 - o *Electricity*: Rural communities in developed countries are usually connected to the national power grids and even isolated communities (as islands) have their own local grids; on the other hand, in low(er) developed countries electricity grids are scarce and are not extended to rural communities. Even in EU countries there are rural communities without grid connectivity, as e.g. in Romania where 3% of the villages are still without electricity, [5]. Hereby,

implementing renewables in a local grid may prove a feasible alternative vs. the extension of the national distribution system.

- *Thermal energy*: most of the rural communities are not using centralized heating systems and have individual systems for domestic hot water (DHW) production (if any). These systems are mostly relying on biomass or on local gas distribution networks, [6]. The use of local wastes (from household and agriculture) could in this situations support the biomass route, while the use of solar or geothermal RET could well meet the entire thermal energy demand.
- *Fresh water* represents one of the most important problems of humankind as more than 40% of the world population (mainly in rural areas) have no direct access to safe drinking water, [1]. Where fresh water is available, the traditional rural approach (supporting the autarchic family concept) supported the widespread of the individual/per house water sources from fountains/drills, using the underground water sources. However, this approach does not support sanitation and requires an additional investments for getting current water at the tap. This is why local networks were developed for water supply, having the advantage of quality control, thus increasing health and well-being (two of the most important sustainable development indicators). However, this approach is not possible when fresh water is scarce (as in arid regions), or water treatment/sanitation is not affordable, as in large and very poor rural parts of the world; in these cases water is considered as one of the most important endangering factors for the (sustainable) development, [2]. This is why solutions for local water disinfection are very much investigated, including the solar distillation or desalination, [10], and advanced oxidation processes based on solar radiation, [12].
- *Wastewater*: communal wastewater treatment plants, wetlands or ponds represent the recommended solutions, in terms of financial effort (initial investment and O&Ms) and as mitigating the environmental and health risks. This solution is common in “urban like” rural communities. However, even in US more than 25% of the rural areas have no community sewage systems. Another alternative much larger implemented implies the decentralized treatment at house/business levels, ranging from performant equipment (based on biological treatment) to sewage septic systems. The latest, currently having the broadest implementation, have a cumulative and significantly negative impact on the underground water source. Considering the global water stress, wastewater (grey water) treatment toward re-use in agricultural purposes (irrigation) represents a sustainable feature, specifically recommended to be included in the sustainability scenarios. Conventional and non-conventional process based on local resources can be integrated to get efficient and feasible technologies, implemented at community scale, thus avoiding the large scale plants, [13].
- ***the level of economic development***: there are large disparities among rural communities in terms of economic development. The road to sustainability has to be supported also by the community, and this rules out (at least in the beginning) the communities with a very low development status. For these communities, “emergency” solutions are reported, to solve the most urgent/critical problem, usually related to fresh water and/or electricity.

Several trends can be outlined, as being important in planning sustainable energy in communities: (1) the population involved in rural activities is decreasing and this is an irreversible trend that, e.g. in EU-15 countries took about 30 years and resulted in about 3% of the population employed in agriculture as compared to the starting 30% percentage; this trend is registered also in Romania as result of social and economic factors but also as result of changing the agriculture pattern towards large farms or community associations, [3]. Another aspect is that the usual income in

rural activities is less than in the urban areas (on average, in Romania, the rural income per capita represents about 56% from the one get by cities inhabitants, [4]). This makes the transition towards sustainability more difficult and asks for efficient solutions, giving use to as much as possible of the local existent resources; this also implies that sustainability should be consider as a business case, able to support community development, to provide jobs, and eventually welfare.

In planning a sustainable rural communities the further economic development must be foreseen as being part of the future energy demand but also as a possible source of additional energy resources (e.g. wastes), [14]. A trend that mitigates the urban-rural disparities considers the development of small local industries and/or tourism that – if well planned and managed – will support a synergistic economic development in rural associative structures, [21]; recently, a novel concept was proposed: a Community Company for Sustainability, able to manage the planning, implementation and operation of sustainable energy systems for the sole benefit of the community, [18];

- **the level of social development** represents another complex indicator that has large variations among communities, being related to the economic level. This indicator is important as it has been proved by decades of project-based efforts that sustainable development actions are lasting only if the community accepts and is directly involved in these changes, [15]. The “help to help yourself” concept well functions in this respect, and should be watched as part of any support scenario, [2]. Additionally, the community involvement is conditioned by tangible advantages, well explained and well communicated; this process – output – outcome management was analysed and proved successful in small communities, [8].

The transition towards sustainable rural communities must integratory consider these aspects (and other more). Considering the man pillars of sustainable development (economy, environment and society), the links between the technical aspects that primarily should be considered are presented in Fig. 1.

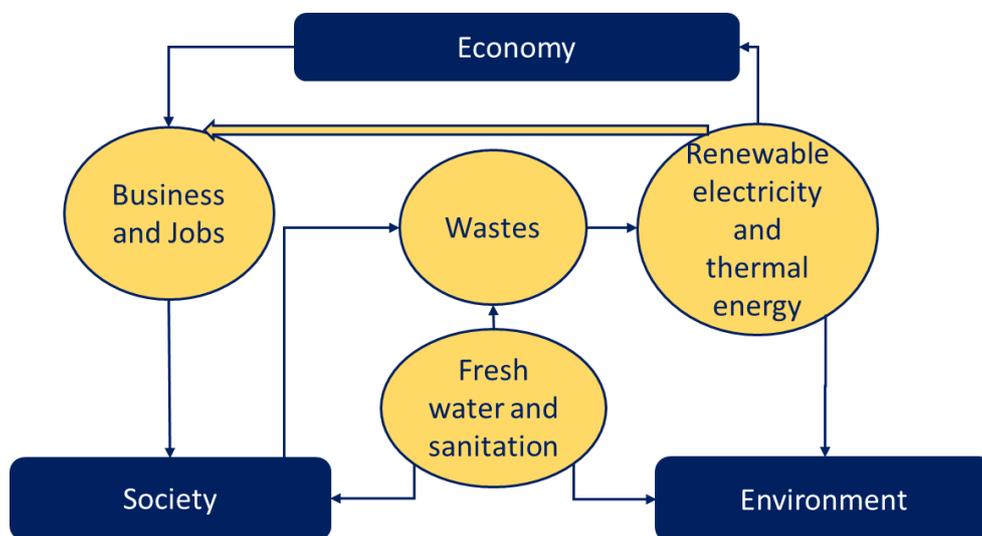


Fig. 1. Integrated approach in the sustainable rural development

SCENARIOS FOR DEVELOPING SUSTAINABLE RURAL COMMUNITIES

Previous work outlined a general methodology that should be followed in developing sustainable communities, [19]. For developing sustainable rural communities, this three-steps methodology specifically asks for:

Step 1. Evaluate the current and provisioned energy demand

To evaluate the current energy demands is rather easy in communities that are connected to local/national utility grids, and actually represents the sum of the electricity, thermal energy and water needs for the built environment (households and public buildings), agricultural activities, tourism, local industries, etc. Any utility covered through centralized distribution systems will follow this accurate estimation path. However, if there are not such distribution facilities, the energy demand can be estimated based on regulatory standards (for thermal energy and fresh water) or on the provisioned electricity consumers.

The near and medium future energy demand of the sustainable rural community should be forecasted based on economic development scenarios, including the energy that compulsory part of any business plan.

Additionally, rural economy involves mobile appliances (e.g. pumping for irrigation) that hardly can be grid connected (or with too large costs), for which mobile RES (as photovoltaics) can be employed.

In a rural community the built environment is the largest energy consumer, with over 70% of the total consumption; therefore it is important to estimate the level of the buildings efficiency and to consider refurbishing as a compulsory step in developing sustainable communities. In a EU household, thermal energy consumption represents on average 65% from the total, therefore refurbishing will firstly target thermal insulation, aiming at reaching the Low Energy Building (LEB) status, that support the technical and economical acceptance (and feasibility) of building integrated renewables, [17]; currently the LEB status (with a total energy demand lower than 60...80 kWh/m² per year) is seldom reported in the old buildings located in the cities; however the rural traditional architecture has many distinct features, developed through centuries as a direct answer to the climatic conditions, which makes buildings quite energy efficient: e.g. thick walls, suitable orientation and controlled access of solar radiation, as Fig. 2 shows. Moreover, there are typical buildings for rural activities (greenhouses) that can be integrated in the household architecture and support the LEB status with buffer spaces. Therefore, before proposing the “standard routine” for refurbishing, one should carefully analyse the traditional local architecture, construction style and multi-functionality.

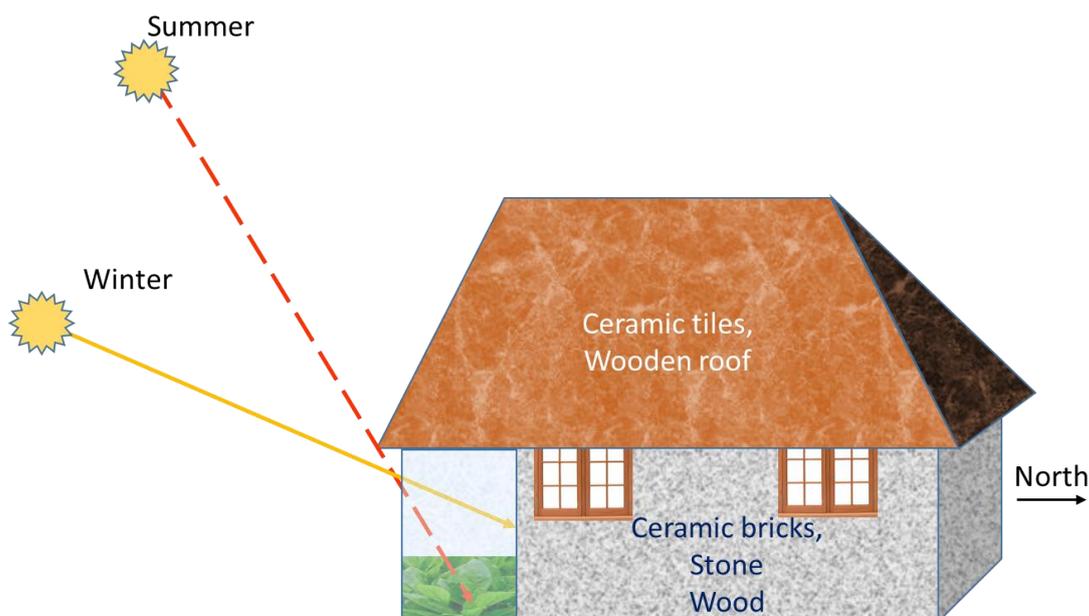


Fig. 2. Passive solar architecture in rural houses

The most important data to be gathered in Step 1 are presented in Fig. 3, as they will be required as input data in Step 3.

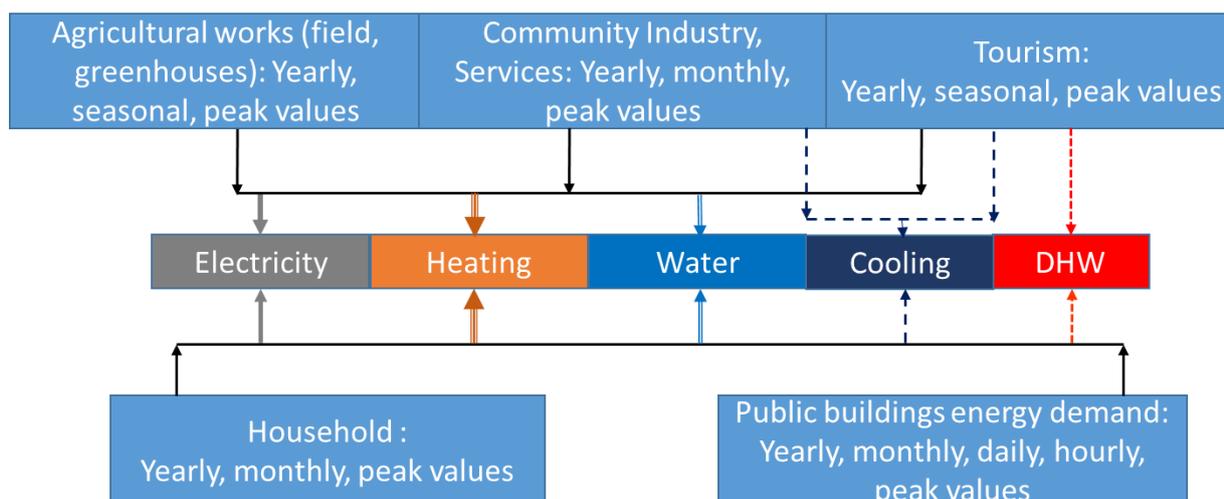


Fig. 3. Structure of the information collected in Step 1

Step 2: Evaluate the available potential of renewable energy sources

The synthesis in Table 1 outlines the most important issues to be considered when evaluating the renewable energy sources:

Table 1
Renewable energy sources in rural communities

Renewable energy source	Availability / Variability	Potential values	Renewable energy system	Output energy /resource
Solar energy	All over the world / Seasonal Spatial	Yearly, Seasonal, Monthly, Peak values	Photovoltaics	Electricity
			Solar-thermal systems	Thermal energy (heating, DHW*, water treatment)
			Photocatalytic systems	Water sanitation
Wind energy	Site-specific / Temporal	Yearly, Monthly, Peak values	Wind turbines	Electricity
			Wind mills	Mechanical energy (water pumping)
Geothermal energy	All over / Constant	Yearly	Ground coupled heat pumps	Thermal energy (heating, cooling)
Hydro-energy	Site-specific / Seasonal	Yearly, Monthly, Peak values	Micro-hydros	Electricity
Cultivated crops biomass	As planned / Seasonal	Yearly, Monthly	Burners	Thermal energy
			Fermentation	Bio-fuels
Crops waste biomass	As planned / Seasonal	Yearly, Monthly	Burners	Thermal energy
Wood cultivated and waste biomass	As planned or as industrial residues / Constant	Yearly, Seasonal	Burners	Thermal energy
			Gasification installations	Electricity
Animal dung, Wastewater sludge	As planned / Constant	Yearly, Seasonal	Dung or sludge digesters	Biogas

(*) DHW: domestic hot water

The accurate assessment of the local/onsite energy sources is required for efficient and cost-effective RES; at least one year records are needed for solar, wind or hydro resources, while biomass estimation should be corroborated with the farming cycles or forestry works. The geothermal potential is almost constant all over the year.

Storage represents an important issue for any energy source and type. Solar and wind energies cannot be stored as such, therefore the potential values should accurately reflect their variability over the seasons, months and for an accurate design daily and hourly predictions should be tackled. On the other hands, the biomass resources are traditionally stored, therefore monthly production values are meeting the design requirements. These average and peak values represent input data in designing the energy mixes (Step 3).

Step 3: Develop the sustainable energy scenarios

Based on the onsite available renewable energy sources and on the current and foreseen demand, various scenarios can be developed as energy mixes that involve hybrid systems (e.g. photovoltaics – wind turbines) or co-generation systems as those based on wood biomass. The list in the design pre-requisites will use as input the data gathered in Step 1 and Step 2, specifically divided on electricity, thermal energy (DHW, heating and cooling), fresh and wastewater demand and will include:

- **the share of the energy demand that will be covered by renewables;** in a first stage this share should be at least 50% from the total energy consumption, considering re-furnished buildings; further on, by re-investing the benefits/savings this share should be increased. Different shares can be allocated to the different utilities, according to the specific location (demand), grid connectivity, etc.
- **the selected renewable energy sources (onsite available) and wastes** that can be used as second raw materials in the energy production. The analysis should be jointly developed by matching, over one year, the complementary resources, able to meet the demand. Specific issues should be considered as subjects of improvement: e.g. refurbishing, water distribution and wastewater sewage systems.
- **the RES components in the energy mix;** the analysis will consider both the community needs and the RES functionality: e.g. when selecting a geothermal system (with ground coupled heat pump) to produce thermal energy, there is a need of electricity to insure the functionality, [20]. Based on the mostly used RES, Fig. 4 outlines the possible hybrid systems for electricity and thermal energy production but also the possible energy mixes, considering the thermal to electricity conversion (via steam) or vice versa, using a thermal fluid.

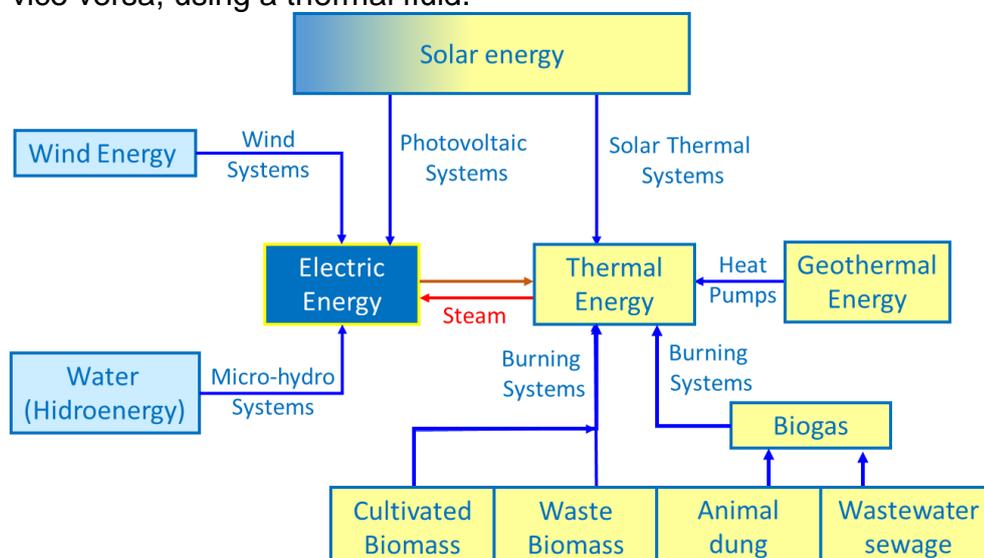


Fig. 4. Hybrid systems and energy mixes based on RES

- ***the size of the RESs in the energy mix and their distribution***, i.e. community centralized systems (wind farms, PV parks, heat pumps fields, micro-hydros) or decentralized systems at the level of a building or of a small buildings group. The EU Sustainable Energy Technologies (SET) plan recommends large community facilities for electricity production (especially in grid connected areas) and built integrated thermal energy facilities (to cut the losses during distribution). However, merging the RES facilities able to meet the thermal energy demand of a few households can bring significant savings in the initial investments for the storage and distribution equipment without increasing the losses, if suitably implemented at a convenient distance to the end-users. This is particularly suitable for solar-thermal systems with concentrated collectors and for dung/sludge bio-gas digesters. Beyond these, local issues should be considered, one of the most important being the available implementation areas; these should consider the land that can be used for RES implementation (vs. agriculture activities), the area of suitably oriented roofs and rooftops, building facades, yards, etc.
- ***optimization and synergies*** will make the difference in insuring efficient and affordable RET solutions. Several examples are:
 - if selecting solar-thermal systems for DHW all over the year, dimensioning will consider the worst-case scenario (i.e. during the short, cold days in winter, with low solar radiation input). This will leave an excess of heat during summer that could be used in an associated crops/fruits/vegetables drying installation;
 - public buildings have a regular daily program, thus there is a typical consumption period, outside which there is a much lower energy demand; supported by a smart control, these buildings are good candidates for savings and passive solutions, while insuring the inner comfort (e.g. night-cooling).

The conceptual design will be further developed allowing a preliminary financial analysis: initial investments, payback time, associated incentives (as much as these can be foreseen), etc. A certain flexibility is associated to defining the energy scenario, considering the correlations between the renewable energy mix - initial investments - savings (CO₂ and energy) - incentives etc. Based on the community's options, the appropriate scenario will be selected and will support the detailed design.

CONCLUSIONS

This paper presents an overview of the most important technical issues that have to be considered in the development of sustainable rural communities.

Based on the analysis of the specific features that differentiate rural from urban communities, the paper outlines the need for tailored solutions, according to the onsite renewable energy potential (accurately assessed) and community requirements.

The paper focuses on the analysis of sustainable solutions able to meet the electricity, thermal energy and water demands in a rural community, with specific details for the main functionalities that can be met in rural areas: household, public buildings, agricultural works, local industries, tourism and services.

A three-step methodology is detailed for the design of hybrid systems or energy mixes based on renewable energy systems. To increase the widespread implementation and the community commitment, complementary functionalities have to be met and several examples are detailed.

The accurate design of RES – based energy mixes supports feasibility and affordability and represents a pre-requisite for the sustainable development of rural communities.

As implementing sustainable communities is an urgent matter and represents a target set by almost each country in the world, there are plenty of dedicated national or continental programs and financial schemes. Thus, once getting the detailed design of a

sustainable rural community, the feasibility study and the revenue scheme, the community can successfully apply for support.

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REFERENCES

- [1] Bouabid A., Louis G.E., Capacity factor analysis for evaluating water and sanitation infrastructure choices for developing communities, *Journal of Environmental Management*, Vol. 161, pages 335-343, September 2015
- [2] Briscoe, J.; Ferranti, D. de, Water for rural communities: helping people help themselves, in: *Water for rural communities: helping people help themselves*, The World Bank, Washington DC, 0-8213-0964-1, 1988
- [3] Ciutacu C., Chivu L., Andrei J.V., Similarities and dissimilarities between the EU agricultural and rural development model and Romanian agriculture. Challenges and perspectives, *Land Use Policy*, Vol. 44, pages 169-176, March 2015
- [4] Chivu L., Ciutacu C., Georgescu L., Household Income in Romania. A Challenge to Economic and Social Cohesion, *Procedia Economics and Finance*, Vol. 22, pages 398-401, 2015
- [5] Cristina A.F., Manescu C., Dumitrescu C., Mateoc Sirb N., Renewable energy – As future alternative for the Romanian rural communities, *Journal of Biotechnology*, Vol. 208, Supplement, pages S115-S116, August 2015
- [6] Dhillon R.S., von Wuehlisch G., Mitigation of global warming through renewable biomass, *Biomass and Bioenergy*, Vol. 48, pages 75-89, January 2013
- [7] Doukas H., Papadopoulou A., Savvakis N., Tsoutsos T., Psarras J., Assessing energy sustainability of rural communities using Principal Component Analysis, *Renewable and Sustainable Energy Reviews*, Vol. 16, Issue 4, pages 1949-1957, May 2012
- [8] Forrest N., Wiek A., Success factors and strategies for sustainability transitions of small-scale communities – Evidence from a cross-case analysis, *Environmental Innovation and Societal Transitions*, Available online 15 June 2015
- [9] Fraker, H., *The Hidden Potential of Sustainable Neighborhoods: Lessons from Low-Carbon Communities*. Island Press, Washington U.S. 2013
- [10] Kabeel A.E., Omara Z.M., Younes M.M., Techniques used to improve the performance of the stepped solar still—A review, *Renewable and Sustainable Energy Reviews*, Vol. 46, pages 178-188, June 2015
- [11] Lau L.C., Lee K.T., Mohamed A.R., Global warming mitigation and renewable energy policy development from the Kyoto Protocol to the Copenhagen Accord—A comment, *Renewable and Sustainable Energy Reviews*, Vol. 16, Issue 7, pages 5280-5284, September 2012
- [12] Malato S., Maldonado M.I., Fernández-Ibáñez P., Oller I., Polo I., Sánchez-Moreno R., Decontamination and disinfection of water by solar photocatalysis: The pilot plants of the Plataforma solar de Almeria, *Materials Science in Semiconductor Processing*, Available online 31 July 2015
- [13] Matos C., Pereira S., Amorim E.V., Bentes I., Briga-Sá A., Wastewater and greywater reuse on irrigation in centralized and decentralized systems — An integrated approach on water quality, energy consumption and CO₂ emissions, *Science of The Total Environment*, Vol. 493, pages 463-471, September 2014,
- [14] Pode A., Diouf B., Pode G., Sustainable rural electrification using rice husk biomass energy: A case study of Cambodia, *Renewable and Sustainable Energy Reviews*, Vol. 44, Pages 530-542, April 2015

[15] Rae C., Bradley F., Energy autonomy in sustainable communities—A review of key issues, Renewable and Sustainable Energy Reviews, Vol. 16, Issue 9, pages 6497-6506, December 2012

[16] Romero-Rubio C., de Andrés Díaz J.R., Sustainable energy communities: a study contrasting Spain and Germany, Energy Policy, Vol. 85, pages 397-409, October 2015

[17] Visa I., Moldovan M., Comsit M., Duta A., Improving the renewable energy mix in a building toward the nearly zero energy status, Energy and Buildings, Vol. 68, Part A, pages 72-78, January 2014

[18] Visa I., Duta A., Community company for sustainability – an innovative tool for implementing renewables, Proceedings of the Romanian Academy for Technical Sciences, 2015 (accepted for publication)

[19] Visa I., Duta A., The built environment in sustainable communities, in sustainable energy in the built environment – Steps towards nZEB, Springer Proceedings in Energy, pages 3-30, 2015

[20] Visa I., Jaliu C., Duta A., Neagoe M., Comsit M., Molodovan M., Ciobanu D., Burduhos B., Saulescu R., The Role of Mechanisms in Sustainable Energy Systems, Transilvania University Publishing House, 2015 (ISBN 978-606-19-0571-3)

[21] Zahedi A., Otterpohl R., Towards Sustainable Development by Creation of Green Social Entrepreneur's Communities, Procedia CIRP, Vol. 26, pages 196-201, 2015

[22] <https://sustainabledevelopment.un.org/topics/ruraldevelopment/decisions>

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