Manuscript submitted to: Volume 3, Issue 2, 241-254.

AIMS Energy DOI: 10.3934/energy.2015.2.241

Received date 03 April 2015, Accepted date 09 June 2015, Published date 15 June 2015

Commentary

Sustainable or Distributed Energy—or both?

Clarifying the Basic Concepts of Reforming the Energy Sector

Pekka Peura [1,*] and Patrik Sjöholm [1,2]

[1] Levón Institute, University of Vaasa, PO Box 700, 65101 Finland
[2] Present address: Wärtsilä Finland Oy, Järvikatu 2-4, 65100 Vaasa, Finland

* **Correspondence:** Email: pekka.peura@uva.fi; Tel: +358-2944-98206.

Abstract: This paper clarifies the concepts of Sustainable Energy (SE) and Distributed Energy (DE) including their related synonyms, by discussing, analyzing and presenting recommendations. This is important because these concepts are crucial in the on-going transformation from the fossil carbon based to renewable energy based societies, but still the use of the concepts has been confusing. SE consists of the integration of rational use of energy (energy saving, energy efficiency, use of renewable energy sources and sustainability management for anticipating, avoiding and reducing adverse impacts). The best consensus for defining DE is "facilities connected to the distribution network or on the customer side of the meter". Devices using fossil fuels but otherwise falling under this umbrella cannot be excluded from DE. This paper explores definitions of wind power in relation to its grid connections via DE. SE is more comprehensive embracing the whole field of energy management, with the exception of distributed fossil generation. SE is valuable for understanding, planning and implementing energy strategies in the transition process of the energy sector. SE also includes centralized energy. It is useful for planning at national or sub-national geographic regions. The combination Sustainable Distributed Energy (SDE) is excellent for regional contexts and for creating regional renewable energy self-sufficiency, integrated with society-wide energy saving and energy efficiency programs.

Keywords: sustainable energy; distributed energy; decentralized energy; renewable energy sources (RES); rational use of energy (RUE)

Abbreviations

CE: Centralized Energy; DE: Distributed Energy (also Decentralized E; Dispersed E); RE: Renewable Energy; RES: Renewable Energy Sources; RUE: Rational Use of Energy; RUoE: Rational Use of Ecosystems; RUH: Rational Use of Humans; RUM: Rational Use of Materials; SDE:

Sustainable Distributed Energy; SE: Sustainable Energy.

1. Introduction

The energy sector is experiencing numerous transformations. Over the last two decades there has been increasing awareness and aspirations to implement widespread use of renewable energy sources (RES) in production of energy. Also the importance of energy saving and energy efficiency have been underscored as being the essential compliment to transformation to RE; both are under the umbrella of "rational use of energy" (RUE). Therefore, Sustainable Energy (SE) is based upon the RUE, which is accomplished through society-wide improvements in energy efficiency, and full reliance upon RES.

Today, there are a number of positive drivers for SE, including:

- The RES potential is abundant
  Empirical material from Europe and globally demonstrates that there is realistic and easily mobilised potential for RES to enable energy self-sufficiency and to satisfy today's energy demand even globally (for review and references cf. [1–3]; references include e.g. [4–18]).
- The economy of RES technologies is already mainly feasible
  The business case for RES, including investments [1,19] and benefits beyond business profitability can be significant. The regional added value (monetary aspects, reduction of costs, increase of purchasing power, new employment, tax income, social, ecological and ethical aspects, improved vitality) would be remarkable if all the money which currently flows out remained within the region (observed e.g. by [19–29]).
- General perception and policies are positive
  Positive general perception and social acceptance of RES since early 1980's [30], policies and other support frameworks [31] have lifted RES to the top of the international political agenda [32], and institutionalisation of SE is occurring globally [2].
- The evolution of technical solutions is a long process
  Technical evolution is still in its early development phase, but new solutions emerge and are installed on a constant basis. According to a recent historical diffusion analysis [33], however, RES technologies have a high overall diffusion potential to cover up to 60% of all produced energy in 2050 globally.

However, the diffusion of SE and RES has been slow and far less than, for instance, the increase of world coal production [34], and there are also many barriers.

- Institutional opposition is strong
  The prevailing large actors tend to prevent any development that is not in support of their own business [35], and RES based solutions are, in effect, fighting against existing energy utilities and structures.
- Value chains are still immature
  The process for change is a prerequisite for SE to reach wider attention and it has only taken its early steps. There is still a clear and separate need for value chains to develop in order to create the markets, i.e. supply and demand. Regardless of the actors in the chains being public or private, a clear distinction needs to be in place for everyone to identify responsibilities, duties, and rights in the market.

- Diffusion of RES based technologies is a long process
  The diffusion of RES based energy self-sufficiency and larger scale RES based energy management systems mean in many cases a total change from fossil fuels to the use of new raw materials. This innovation requires new technologies and institutional frames (cf. supporting arguments: e.g., [36–42]). The shift towards these structures, different from the prevailing centralized system, will be a long-term process. RES solutions are in the early phases of diffusion. Still, the concurrence always takes place in real time markets, where the opponents are at the opposite end of their diffusion. This means that they are competing against technologies with many years of operation and technical evolution, where investments have been repaid, supportive social structures are in place and where all the benefits of mass production and pre-established value chains exist.
- The whole development is an evolutionary time consuming process
  Change itself towards SE will be a long evolutionary process at local, regional, national and international levels. The process will need to involve the majority of people and there will be a huge number of decision-makers, from individual citizens, families, farmers and businesses, to the public sector. This process will need to involve those who consume and produce energy, those who manufacture the technical solutions, those who deliver the raw materials and those who create the general preconditions for the whole movement [2,43]. The success of this process depends primarily on how the different levels and crucial stakeholders engage [30].

The idea of more widespread use of RES solutions has been closely connected to the strategy of smaller scale technical solutions named distributed or decentralized generation or energy (DE). Usually writings concerning distributed energy implicitly mean generation of RES to energy. However, we might ask: Is not fossil fuel generation in smaller scale plants or by small engines, for instance, also distributed generation of energy? Correspondingly, it is even more common, that larger scale power plants, representing the centralized energy system, are adopting RES as their fuel – then, would this fall under the concept of SE? There is clearly confusion in using the basic concepts even in academic writings concerning the development of the energy sector.

This paper aims at clarifying the basic concepts of Sustainable Energy (SE) and Distributed Energy (DE), including its different synonyms, and their use by discussing, analysing and making concluding remarks. This scope is important because of the significance of these concepts in the on-going transformation of the whole energy sector, but also because of the confusion in their connotations and use in scientific discussions. The analysis results in recommendations for integrative use of the concepts. As SE has recently been reviewed and redefined [2], the main emphasis in this paper is in DE.

2. Definitions: Sustainable Energy and Distributed Energy

2.1. Sustainable Energy

Sustainable Energy (SE) has become one of the key concepts in reforming the energy sector in the EU and worldwide. As the production of energy has caused major impacts on the environment, "*Renewable energy is one of the most efficient ways to achieve sustainable development*" [44], and "*One of the main tasks in this century (...) will be to manage a transition process towards a* *sustainable energy system*" [45]. The concept of SE was recently broadly reviewed, and it was redefined [2] as follows:

1 Rational Use of Energy (RUE); energy efficiency and saving
2 Renewable Energy Sources (RES); materials and other sources (biomass, wood, hydro, solar, geo, wind etc.)
3 Integration of RUE and RES
4 Sustainability management

There are a number of technologies for both RUE and utilising RES. They can be implemented alone as separate solutions or designed to be used as a combination. The integration of RUE and RES technologies (some examples indicated in Figure 1) will be the key to complete solutions. With different combinations of the available RUE and RES technologies and regional RES energy it is possible to outline solutions with different degrees of energy self-sufficiency. This concept can be applied to any target building, company, community, region, or nation or groups of nations.

Figure 1 illustrates how the SE concept can be composed in practice. The starting point is implementing RUE technologies. Then, the energy which cannot be saved or upgraded and is needed is produced by RES. RES can consist of a number of raw materials or other sources, which are formed or can be collected. These sources can be utilised using several technical, management, policy and economic approaches.

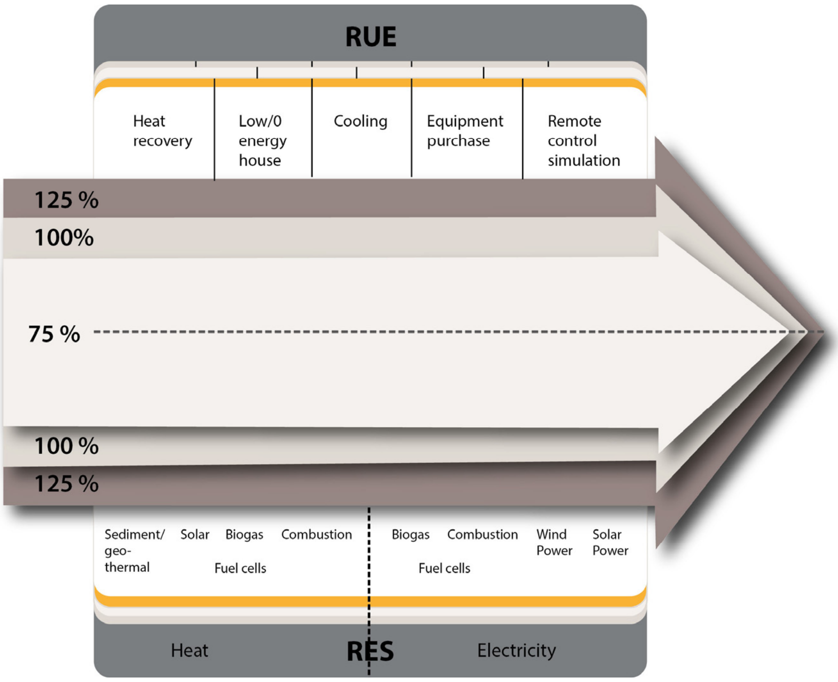

Figure 1. The concept of Sustainable Energy consists of the Integration of RUE (rational use of energy) and RES (renewable energy sources), where different combinations can produce different degrees of energy self-sufficiency [2].

It is also essential to establish management systems for implementing sustainable energy strategies and separate projects. There is always a danger that these projects become a new field of ecological colonialism where the old pattern of robbery [2,3] will take over. A number of examples have already been reported [46,47], where maximal economic gain and carelessness of the environment have been applied for producing renewable energy in the name of sustainability. This must be prevented by regulations. Then we also need policies that are clear and are enforced equitably, and we need new societal education on many ethical facets [48].

This means that an important precondition for adopting truly sustainable energy systems is that a managing body will be established, which is accompanied with the creation, implementation, monitoring and enforcement of rules for all market actors to ensure that sustainability will actually be respected when producing and using energy. These "rules of the game" should be based upon standardization of energy products (e.g. zero carbon energy, like wind) and energy production parameters (e.g. respect of the local, regional and global environment), human health etc. [48].

2.2. Distributed Energy

2.2.1. General definitions

There are a number of definitions and analyses concerning the concept of Distributed Energy (DE). Most often it has been understood as generation of electricity in "smaller scale" units, which, however, has proved far from satisfactory as a definition. There are several terms for this kind of strategy such as:

- Decentralized energy or generation; mainly in Europe and Asia [49,50];
- Dispersed; mainly in North America [50–52];
- Embedded; mainly in South America [50,52];
- On-site [50,52].

This section reviews and summarises some of these definitions. In this paper we use DE alone, and the eventual overlapping and differences are indicated wherever it is needed. Some frequently used definitions in scientific literature are collated in Table 1. A general observation is that there is neither consensus nor a settled and agreed definition, although for instance Ackermann et al. [49] and Pepermans et al. [52], who both have reviewed many definitions, agree upon the criteria and grounds for the definition of DE with their statement.

All definitions suggest that at least small-scale generation units connected to the distribution grid fall underneath the umbrella of DE. The same applies also to generation units installed close to the load or at the customer side of the meter (cf. also [55]). There are also larger generation units installed on customer sites that are connected to the transmission grid [55]. Ackermann et al. [49] and Pepermans et al. [52] concluded that the following criteria are not valid for defining DE: generation capacity or rating, generation technology, mode of operation, ownership of the generation units, environmental impacts, and the penetration level (regional degree of independence or "saturation" by DE). These aspects are frequently connected for describing DE but are not adequate in defining DE.

This leads to the definition proposed by Ackermann et al. [49], where the definition is made in terms of connection and location rather that of generation capacity or technology [55]: "*Distributed generation is an electric power source connected directly to the distribution network or on the customer site of the meter*". This definition does not differentiate between raw materials or sources, which means that fossil fuels cannot be excluded from the definition [52].

2.2.2. Case: Wind power

Wind power is a good example of RES that has traditionally been considered “distributed”. It is also an example of how inadequate the DE definitions have been in seeking to properly position wind power. Utilisation of wind power can be done in a number of different ways, ranging in scale from separate small turbines for use by people for their private houses, farms and other buildings, to wind farms consisting of a large number of huge wind turbines, which are integrated into the regional electrical grids.

Table 1. Selected definitions of Distributed Energy.

Source	Contents
[51]	- Maximum capacity 50–100 MW - Usually connected to distribution network - Not centrally planned, not centrally dispatched - Beyond control of the transmission grid operator
[49]	- No limits on technology or capacity of application - Connection and location: Connected directly to the distribution network, or located on the customer side of the meter
[53]	- Small size: ≤ 30 MW - At or near customer sites
[54]	- Usually < 1 kW–tens of MW - Not part of a central power system - Located close to the load - Includes storage
[55]	- On a customer’s site or connected to distribution network - No reference to the generation capacity
[50]	- Small size, compact, and clean electric power generation - At or near an electric load (customer)
[52]	- No limits on technology or capacity of application - Fossil fuels included - “… connected directly to the distribution network or on the customer side of the meter”
[56]	- Size: “sufficiently smaller than central generating plants” - Location: “interconnection at nearly any point in a power system”
[57]	- “Electricity production at or near the point of use, irrespective of size, technology or fuel used – both off-grid and on-grid”

The use of smaller wind turbines at homes, farms, businesses, and public facilities to off-set all or a portion of on-site energy consumption is clearly DE, commonly referred to as small and community wind [58]. In the USA, wind turbines are defined as DE when their capacity if below 100 kW, while in Europe, turbines with turbine blades diameter of less than 200 m belong to DE [59]. The National Wind Coordinating Committee [60] considers that all turbines with capacity below 5 MW produce DE. This definition actually covers nearly all existing wind turbines at the moment.

Probably, at least one of the reasons why wind power is generally considered DE is its typical characteristic of geographical dispersion of production units. This means that as wind power consists of multiple turbines in different locations, the implicit perception is that it is 'distributed'. However, the location of plants as such does not mean that the production system is based on a centralized or distributed production strategy. Dispersion is also important for managing the risks for periods with no or little wind: by scattering turbines and wind parks geographically, it is more probable that at least some wind energy can be tapped regularly and continuously.

The important differences of applying DE definitions to wind power installations is that wind power systems are mainly defined according to the capacity or size of single turbines, while generally DE is defined by the plant's location or connection within distribution networks. These definitions don't adequately apply to wind parks, which is strange, because the combined output from the individual turbines within the park is usually delivered via one connection, to a high voltage grid. According to the general definitions these kinds of parks should be considered as parts of centralized energy generation.

A concluding attempt to apply the general DE definition for wind power is made below:

- Large wind farms, e.g. tens of 3–5 MW turbines:
  They predominantly deliver electricity to the high voltage grid,
  hence they are part of the Centralized Energy (CE) system;
- Small wind farms, e.g. <10 turbines each 1–2 MW:
  Can deliver electricity to the distribution network or to the high voltage grid,
  hence they can be either DE of CE depending on the predominant strategy of delivery;
- Separate large turbines, e.g. 1–2 turbines each 3–5 MW:
  They predominantly deliver electricity to the distribution network,
  hence they are DE with the option of acting also feeding into the grid, thus they can be considered to be part of the CE system;
- Small separate turbines, "small and community wind".
  They produce electricity for households and small communities,
  hence they are supplying DE.

From these differences, when it comes to wind energy, the general definitions of DE can be applied, although there can be some confusion between and even within the different alternatives. It is important that in each case the predominant way of delivering energy is defined, and then the "strategic location" of either DE or CE can be decided, whenever it has importance. It must be underscored that smaller systems, even small communities, while acting mainly as DE, can have the option of selling excess electricity from their system and retain the form of DE.

These differences are relevant for understanding the way of societal progress toward rational approaches to catalyzing the transition to sustainable societies built upon energy efficiency and renewable energy, as also pointed out by professor Donald Huisingh [48]. It is important to realize that the main "energy feasibility" for rural societies, for instance, comes from production of their own, which is different from today's centralized way of production where all benefits flow out from these societies.

There are also concepts of Sustainable consumption and Production that are relevant. "... *energy efficiency also means reduction in production and usage of useless products, that are obsolete or are thrown away within short times after being purchased. One must then not only address improvement in energy efficiency in transportation, operation of heating and cooling systems in buildings, etc. but issues such as the embedded* energy *in the lives cycles of all of the products that are used in society. That opens many more dimensions of the RUE, which must be integrated within the RUM (rational use of materials) as well as RUoE (Rational Use of Ecosystems) and finally, RUH (rational use of humans)*" [48]. These important aspects are however beyond the scope of this paper.

3. Discussion

Sustainable Energy (SE) and Distributed Energy (DE) are central and very important concepts in the on-going comprehensive and rapid transition of the fossil based energy sector towards RES (renewable) based generation of energy and post-fossil carbon societies. These concepts are widely used in a number of contexts—from practical discussions and popularised writings to academic articles—but mostly their definitions have been deficient. Usually they have been used separately, but sometimes they have been integrated in one way or another. The main differences and similarities are briefly discussed in Figure 2.

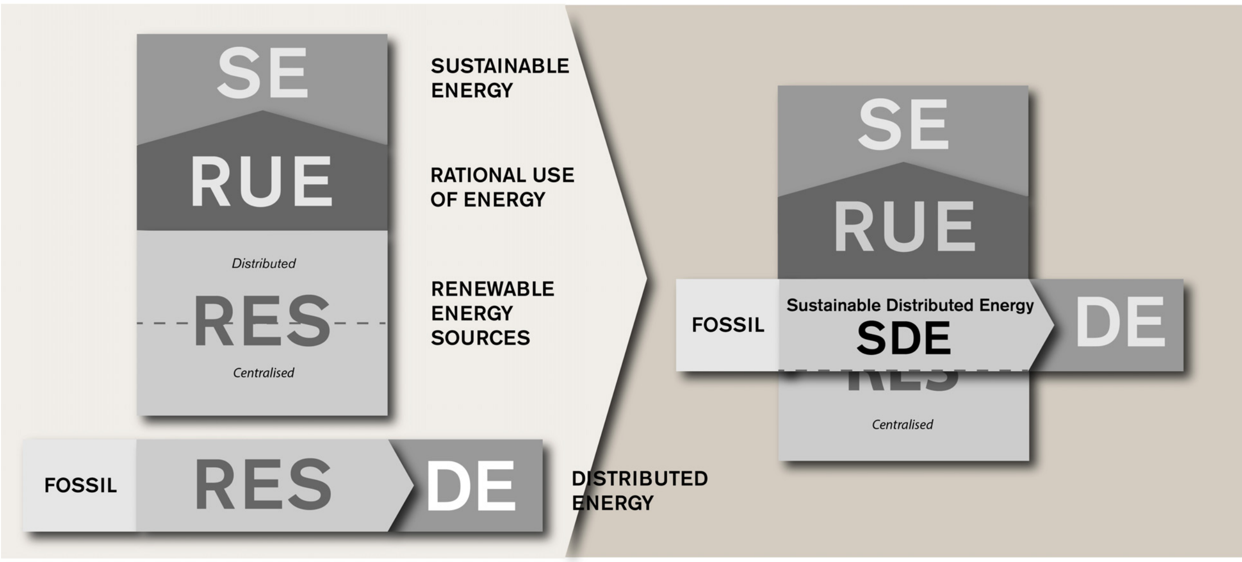

Figure 2. The key relationships between Sustainable Energy (SE) and Distributed Energy (DE) can be structured in terms of RUE, RES including distributed and centralized strategy, and fossil energy production.

Usually, DE only refers to production of energy, and thus, RUE is not relevant to the narrow definition of DE, while SE also includes RUE. Correspondingly, DE is the concept used for generation of electricity, but SE involves the whole energy system. However, as "heating" cannot be transmitted long distances, it is always "distributed" by definition. This also applies to district heating networks, which are local or regional and feed heat energy into to distribution networks, even if the electricity from the same production units may be delivered to the national grid.

In terms of defining DE versus CE, the distinctive feature is whether the plant predominantly feeds electricity into the transmission grid, or electricity for local use, using renewable raw materials and other sources from the local region for local use.

The use of RES from the local region refers to the distributed energy strategy. There are, however, a number of examples in which also large centralized energy production units adopt RES for their raw material production by making new investments or by transforming older plants for the use of RES. This is a question of technical and economic optimisation. Centralized energy clearly falls within the definition of SE when it is based on RES, either by new devices or by change of raw materials for use in older devices. DE, in turn, can include also smaller scale fossil power generation to distribution networks, which is importantly different from SE.

According to this short analysis, SE is more comprehensive than DE by embracing the whole field of energy management, with the exception of distributed fossil power generation. This leads us to suggest that SE is a sound concept for understanding, analysing, planning and implementing energy strategies in the urgently needed transition to post fossil carbon societies. As SE also includes centralized energy, it as a whole fits well for national or other geographically large perspectives. The combination or "hybrid" Sustainable Distributed Energy (SDE) would be excellent for local and regional contexts and, for catalyzing regional self-sufficiency based on the use of the regions' own RES, accompanied with energy saving and energy efficiency programs.

Historically, DE including local storage used to be the predominant way of generating electricity. Structures in the energy sector evolved towards larger units and more centralized generation, and towards disappearance of small-scale generation units. The scale of production was enabled by fossil fuels with high energy content, large reserves and massive global logistical systems. This, in turn, enabled huge industries and scale of economy, where the grid evolution had to accomplish long distance transmission, at high voltages, of large quantities of energy generated from large centralized energy transformation systems. Consequently, small-scale units gradually disappeared.

In the last two decades DE is returning to the scene [52] for a number of reasons and drivers. The general perception is that the fossil reserves are limited, although they still would be sufficient for some generations [34]. Also the problematic of climate change has forced nations to adopt new "low fossil carbon" policies, strategies, and consequently regulations and practical actions. General opinion favours RES [30,2], and gradually its political and social acceptance has raised a new kind of customer behaviour and customer demand. Other contributing factors have been market liberalisation and development of new, small-scale technologies [52].

However, SE, DE and the use of RES have met with severe challenges that are linked to the prevailing market structures, and which Pepermans *et al*. [52] neatly crystallise: "*If only wholesale market liberalisation is achieved, electricity customers would essentially be faced with a monopolist at the distribution level. This monopolist can easily discourage the installation of distributed generation. (...) Grid operators that own generation capacity also have an incentive to discriminate against distributed generation.*"

Information on fossil reserves give the false illusion that resources are unlimited globally [34,3], but due to increasingly urgent evidence of climate changes due to rapidly increasing carbon dioxide concentrations in the atmosphere is beginning to drive development to shift to post fossil carbon technologies, policies and societal systems based upon RES. This will have a number of consequences from the perspective of size and location of production units, for instance. Most of RES supplies are dispersed and their specific energy content (e.g. bioenergy) is small compared with fossil energy. Both these aspects accompanied with the fact that the whole value chain of RES is still immature, contribute to the perception that transportation beyond long distances is not feasible. This, in turn, affects the whole logistical system.

It seems logical to conclude that mobilisation of RES supplies can best be promoted and stimulated in smaller scale systems. While some central large units have adopted or will adopt RES, in the smaller systems, the distinctive feature will continue to be to generate RES energy from local or regional sources for their own region or regions located near the sources. This is especially relevant for bio-based energy sources, while within the context of the 'Smart Grids' that are evolving for the gathering and distribution of electrical energy from wind, direct solar or geo-thermal utilization of larger scale production units may be more feasible.

This strategic starting point strongly encourages creation and support of regional RES energy self-sufficiency strategies, policies, procedures and pricing mechanisms, which can also contribute to the whole regional and national economy. Simultaneously, this is identical to the definition of the concept of Sustainable Distributed Energy, i.e. generation of energy within distribution networks and using RES as its raw materials and other sources, with the option of delivering excess electricity to the external grid. Thus, SDE can become a central concept for the on-going transformation and future development of the energy sector as it plays a central role in supporting the transition to sustainable, post-fossil carbon societies.

4. Conclusions

This paper analyses and discusses the concepts of Sustainable Energy (SE) and Distributed Energy (DE) including their related synonyms. This is important because these concepts are crucial in the on-going transformation from the fossil carbon based to renewable energy based societies, and because the use of the concepts has been confusing. The main conclusions drawn and the lessons learnt, in terms of defining the concepts and their relationship, are the following:

- DE is 'facilities connected to the distribution network or on the customer side of the meter'; including devices using fossil fuels.
- SE is more comprehensive by embracing the whole field of energy management, with the exception of distributed fossil power generation. SE also includes centralized energy, it as a whole fits well for national or other geographically large perspectives.
- SE is a sound concept for understanding, analysing, planning and implementing energy strategies in the urgently needed transition to post fossil carbon societies.
- Sustainable Distributed Energy (SDE) would be excellent for local and regional contexts and, for catalysing regional self-sufficiency based on the use of the regions' own RES, accompanied with energy saving and energy efficiency programs.

Distributed strategies and Sustainable Energy are returning to the scene of the energy sector. The main reasons are that fossil reserves have shown limited in the long term, and RES reserves have shown more abundant than the earlier perceptions indicated, accompanied with the problematic of climate change, and positive general opinion and political and social acceptance.

RES supplies can best be promoted and stimulated in smaller scale systems. This strategic starting point strongly encourages creation and support of regional RES energy self-sufficiency strategies, policies, procedures and pricing mechanisms, which can also contribute to the whole regional and national economy. This is identical to the definition of the concept of Sustainable Distributed Energy, i.e. generation of energy within distribution networks and using RES as its raw materials and other sources. SDE can become a central concept for the on-going transformation and future development of the energy sector. Thus, it will be important to understand these basic concepts, as this paper attempts to do.

Conflict of Interest

The authors declare that there are no conflicts of interest related to this study.

References

1. Peura P, Hyttinen T (2011) The potential and economics of bioenergy in Finland. *J Cleaner Production* 19: 927–945.
2. Peura P (2013a) From Malthus to Sustainable Energy—Theoretical orientations to reforming the energy sector. *Renew Sust Energ Rev* 19(C): 309–327.
3. Peura P (2013b) *From unlimited growth to sustainable energy. The origins of operational patterns by means of societal selection*. Acta Wasaensia 279. 204 p.
4. Evrendilek F, Ertekin C (2003) Assessing the potential of renewable energy sources in Turkey. *Renew Energ* 28: 2303–2315.
5. Ragwitz M, Schleich J, Huber C, et al. (2005) Analyses of the EU renewable energy sources' evolution up to 2020 (FORRES 2020). Stuttgart: Fraunhofer IRB Verlag.
6. Lewandowski I, Weger J, van Hooijdonk A, et al. (2006) The potential biomass for energy production in the Czech Republic. *Biomass Bioenergy* 30: 405–421.
7. Božičević Vrhovčak M, Tomsic Z, Debrecin N (2006) Potential and use of renewable energy sources in Croatia. *Renew Energ* 31:1867–1872.
8. Schneider DR, Duic N, Bogdan Z (2007) Mapping the potential for decentralized energy generation based on renewable energy sources in the Republic of Croatia. *Energy* 32: 1731–1744.
9. van Dam J, Faaij APC, Lewandowski I, Fischer G (2007) Biomass production in Central and Eastern Europe under different scenarios. *Biomass Bioenergy* 31: 345–366.
10. Verbruggen A, Fischedick M, Moomaw W, et al. (2010) Renewable energy costs, potentials, barriers: Conceptual issues. *Energy Policy* 38: 850–861.
11. Smeets EMW, Faaij AP (2007) Bioenergy potentials from forestry in 2050. *Climatic Change* 81: 353–390.
12. Resch G, Held A, Faber T, et al. (2008) Potentials and prospects for renewable energies at global scale. *Energy Policy* 36: 4048–4056.
13. de Vries BJM, van Vuuren DP, Hoogwijk MM (2007) Renewable energy sources: Their global potential for the first-half of the 21st century at a global level: An integrated approach. *Energy Policy* 35: 2590–2610.
14. Ladanai S, Vinterbäck J (2009) *Global Potential of Sustainable Biomass for Energy.* Swedish University of Agricultural Sciences, Report 013. Uppsala. 29 p.
15. Seiffert M, Kaltschmitt M, Miranda JA (2009) The biomethane potential in Chile. *Biomass Bioenergy* 33: 564–572.

16. Ceciliano R (2010) WBA's report shows: The global potential of sustainable bioenergy is enough to meet the world's total energy needs. *Bioenergy* 3: 4–5.
17. Jacobson MZ, Delucchi MA (2009) A Path to Sustainable Energy by 2030. *Sci Am* 301: 58–65.
18. Jacobson MZ, Delucchi MA (2011) Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. *Energy Policy* 39: 1154–1169.
19. Masini A, Manichetti E (2012) The impact of behavioural factors in the renewable energy investment decision making process: Conceptual framework and empirical findings. *Energy* Policy 40: 28–38.
20. Hillebrand B, Buttermann HG, Behringer JM, et al. (2006) The expansion of renewable energies and employment effects in Germany. *Energy Policy* 34: 3484–3494.
21. Lehr U, Nitsch J, Kratzat M, et al. (2008) Renewable energy and employment in Germany. *Energy Policy* 36: 108–117.
22. Moreno B, López AJ (2008) The effect of renewable energy on employment. The case of Asturias (Spain). *Renew Sust Energ Rev* 12: 732–751.
23. Thornley P, Rogers J, Huang Y (2008) Quantification of employment from biomass power plants. *Renew Energ* 33: 1922–1927.
24. Blanco MI, Rodrigues G (2009) Direct employment in the wind energy sector: An EU study. *Energy Policy* 37: 2847–2857.
25. Hoffmann D (2009) Creation of regional added value by regional bioenergy resources. *Renew Sust Energ Rev* 13: 2419–2429.
26. del Río P, Burguillo M (2009) An empirical analysis of the impact of renewable energy deployment on local sustainability. *Renew Sust Energ Rev* 13: 1314–1325.
27. Openshaw K (2010) Biomass energy: Employment generation and its contribution to poverty alleviation. *Biomass Bioenergy* 34: 365–378.
28. Sastresa EL, Usón AA, Bribián IZ, et al. (2010) Local impact of renewables on employment: Assessment methodology and case study. *Renew Sust Energ Rev* 14: 679–690.
29. Dalton GJ, Lewis T (2011) Metrics for measuring job creation by renewable energy technologies, using Ireland as a case study. *Renew Sust Energ Rev* 15: 2123–2133.
30. Wüstenhagen R, Wolsink M, Bürer MJ (2007) Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy* 35: 2683–2691.
31. REN21 (2011a) Renewables 2011. Global Status Report, Renewable Energy Policy Network for the 21st Century.
32. REN21 (2011b) Renewable Energy in the International Policy Process, Renewable Energy Policy Network for the 21st Century.
33. Lund PD (2010). Fast market penetration of energy technologies in retrospect with application to clean energy futures. *Appl Energ* 87: 3575–358.
34. Jefferson M (2008) Accelerating the transition to sustainable energy systems. *Energy Policy* 36: 4116–4125.
35. Lund H (2010) Renewable Energy Systems. The Choice and Modeling of 100% Renewable Solutions. New York: Academic Press, Elsevier.
36. Unruh GC (2000) Understanding carbon lock-in. *Energy Policy* 28: 817–830.
37. Unruh GC (2002) Escaping carbon lock-in. *Energy Policy* 30: 317–325.

38. Jacobsson S, Johnsson A (2000) The diffusion of renewable energy technology: an analytical framework and key issues for research. *Energy Policy* 28: 625–640.
39. Bergek A (2010) Levelling the playing field? The influence of national wind power planning instruments on conflicts of interests in a Swedish county. *Energy Policy* 38: 2357–2369.
40. Wolsink M (2000) Wind power and the NIMBY-myth: institutional capacity and the limited significance of public support. *Renew Energ* 21: 49–64.
41. Wolsink M (2007) Planning of renewables schemes. Deliberative and fair decision-making on landscape issues instead of reproachful accusations of non-cooperation. *Energy Policy* 35: 2692–2704.
42. Wolsink M (2012) The research agenda on social acceptance of distributed generation in smart grids: Renewable as common pool resources. *Renew Sust Energ* Rev 16: 822–835.
43. Peura P, Kuittinen H, Knuckey L, et al. (2014) Implementing Sustainable Energy—Four case studies. *Int J Sust Economy* 6: 19–44.
44. Goldemberg J (2007) Ethanol for a Sustainable Energy Future. *Science* 315: 808–810.
45. Haas R, Watson J, Eichhammer W (2008) Transitions to sustainable energy systems—Introduction to the energy policy special issue. *Energy Policy* 36: 4009–4011.
46. Blarke MB (2008) *From dusk till dawn. An essay about how the climate crisis has come to define sustainable energy in the context of the Danish experiment*. Aalborg University. 58 p.
47. Moriarty P, Honnery D (2009) What energy levels can the Earth sustain? *Energy Policy* 37: 2469–2474.
48. Donald Huisingh: personal communication, discussion in June 2014.
49. Ackermann T, Andersson G, Söder L (2001) Distributed generation: a definition. *Electr Pow Syst Res* 57: 195–204.
50. El-Khattam W, Salama MMA (2004) Distributed generation technologies, definitions and benefits. *Electr Pow Syst Res* 71: 119–128.
51. CIRED (1999) Dispersed generation. Preliminary report of CIRED working group WG04, June, p. 9+Appendix (p.30).
52. Pepermans G, Driesen J, Haeseldonckx D, et al. (2005) Distributed generation: definition, benefits and issues. *Energy Policy* 33: 787–798.
53. Chambers A (2001) Distributed generation: a nontechnical guide. Tulsa: PennWell, 283.
54. Dondi P, Bayoumi D, Christoph HC, et al. (2002) Network integration of distributed power generation. *J Power Sources* 106: 1–9.
55. International Energy Agency (IEA) (2002). Distributed generation in liberalised electricity markets. Paris. 128.
56. Dreisen J, Belmans R (2006) Distributed Generation: Challenges and Possible Solutions. 1-4244-0493-2/06/$20.00 ©2006 IEEE. Available from: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1709099.
57. WADE (2014) What is DE? World Alliance for Decentralized Energy, 2014. Available from: http://www.localpower.org/deb_what.html.
58. DWPA (2014) Learn about distributed wind. Distributed Wind Association. Available from: http://distributedwind.org/home/learn-about-distributed-wind/. Visited 16.1.2014.
59. BTI (2014) Distributed Wind Energy, 2014. Available from: http://windenergyisrenewable.com/distributed-wind-energy/.

60. NWCC (2014) Distributed Wind Power Assessment, 2014. Available from: http://nationalwind.org/about-nwcc/prior-nwcc-activities/distributed-generation/. Visited 16.1.2014.