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Smart energy systems and 4th generation district heating

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A B S T R A C T

This editorial gives an introduction to the important relationship between Smart Energy Systems and 4th Generation District Heating and presents a number of selected papers from the 1st International Conference on the topic. All of the papers elaborate on or otherwise contribute to the theoretical scientific understanding on how we can design and implement a suitable and least-cost transformation into a sustainable energy future. The concept of Smart Energy Systems emphasizes the importance of being coherent and cross-sectoral when the best solutions are to be found and how this also calls for the active inclusion of the heating and cooling sectors. The concept of 4th Generation District Heating emphasizes that district heating and cooling are both important elements but also technologies that have to be developed further into a 4th generation version to be able to fulfil their roles in future sustainable energy systems. The conclusion is that further development of such theoretical scientific understanding is essential for the implementation of political goals related to future sustainable energy solutions.

1. Smart energy systems

The Smart Energy Systems concept is essential for 100% renewable energy systems to harvest storage synergies across energy subsectors and exploit low-value heat sources. The Smart Energy Systems approach was developed in 2011 as a result of the CEESA project [1]. This project addressed Danish scenarios with a particular focus on renewable energy in the transport system in a context with limited access to bioenergy [2,3] and was founded on extensive experience in holistic and cross-sectoral energy system studies [4–7]. The concept of smart energy systems was first mentioned in the academic literature in a paper in 2012 [8] and then given a formal definition in 2014 [9]. Since then, different papers have used the concept in relation to energy system modelling [11], energy savings [12], sustainable transport [13] as well as for the design of a smart energy system for the whole of Europe [14]. As opposed to, for instance, the smart grid concept, which takes a sole focus on the electricity sector, the smart energy systems approach includes the entire energy system in its identification of suitable energy infrastructure designs and operation strategies. Focusing solely on the smart electricity grid often leads to the identification of transmission lines, flexible electricity demands, and electricity storage as the primary means to dealing with the integration of fluctuating renewable sources. However, these measures are neither very effective nor cost-efficient considering the nature of wind power and similar sources. Kwon & Østergaard [15], for instance, found only very limited potential in flexible electricity demand. The most effective and least-cost solutions are to be found when the electricity sector is combined with the heating and cooling sectors and/or the transport sector. Moreover, the combination of electricity and gas infrastructures may play an important role in the design of future renewable energy systems.

2. 4th generation district heating

The notion of 4th Generation District heating and cooling was first used by Prof. Sven Werner and afterwards given a formal and enhanced definition in a paper from 2014 [16] as a part of the work of the Strategic Research Centre for 4th Generation District Heating Technologies and Systems. The work of the strategic research centre is based on the hypothesis that district heating and cooling have important roles to play in future sustainable energy systems, but in order to fulfil such roles the technologies will have to develop into a new 4th generation. In 2008 and 2010, the Heat Plan Denmark studies demonstrated how this is the case in Denmark [7,17,18] and similar Heat Roadmap Europe studies were subsequently made for the whole of Europe [19,20]. While preceding the notion of 4th generation district heating, these studies employed elements which were subsequently included in the definition of 4th generation district heating.

In its research on low-temperature district heating, the Strategic Research Centre for 4th Generation District Heating Technologies and Systems enhances the understanding of supply system design, infrastructure and heat savings. In future energy systems, combinations of low-temperature district heating resources and heat savings represent a promising alternative to individual heating solutions and passive or energy+ buildings. This change in the heating system also requires institutional and organisational changes [21,22] that address the implementation of new technologies and enable new markets to provide feasible solutions to society.

The development of 4th generation district heating is essential to the implementation of Smart Energy Systems to fulfil national objectives of future low-carbon strategies as well as the European 2020 goals. With lower and more flexible distribution temperatures,

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4th generation district heating can utilise renewable energy sources while meeting the requirements of low-energy buildings and energy conservation measures in the existing building stock.

3. A new theoretical scientific understanding

The important relationship between Smart Energy Systems and 4th Generation District Heating calls for a further development of the theoretical scientific understanding on how to design and implement future sustainable energy systems. The smart energy systems approach emphasises the need for coherent and cross-sectoral thinking which must actively include the heating and cooling sectors in order to find the best solutions. However, the 4th generation approach emphasises that technologies will and should be developed and need to be adjusted to the future conditions of renewable energy-based energy supply. Consequently, there is a need for scientific contributions to both the design of future district heating and cooling systems and technologies as well as contributions to ways of integrating such development into coherent smart energy systems.

This special issue presents selected and peer-reviewed papers from the 1st International Conference on Smart Energy Systems and 4th Generation District Heating (SES4DH 2015), which was held in Copenhagen on 25-26 August 2015. SES4DH 2015 included more than 70 presentations with industrial and scientific inputs from 20 different countries resulting in a programme of large variety and many interesting sessions. Around 20 papers were selected to be published as a special issue in this journal while other papers were published in the International Journal of Sustainable Energy Planning and Management [23–26].

The aim of the conference was to present and discuss scientific findings and industrial experiences related to the subject of Smart Energy Systems and future 4th Generation District Heating Technologies and Systems (4GDH). The conference was organized by the 4DH Strategic Research Centre in collaboration with Aalborg University, Denmark.

4. Content details

The first four papers address the importance of including the heating sector in the design and implementation of future smart energy systems and solutions.

In the paper “Hydrogen to link Heat and Electricity in the Transition towards Future Smart Energy Systems” [27], Nastasi and Lo Basso address the crucial challenge of integrating the increasing share of intermittent renewable energy sources in national energy by linking both heat and electricity production as the key strategy at the urban as well as regional and national scales.

In the paper “The potential of grid-orientated distributed cogeneration on the minutes reserve market and how changing the operating mode impacts on CO_2 emissions” [28], Schüwer et al. analyse the technical potential and ecological impact of CHP (combined heat and power) systems on the German minute reserve market for 2010, 2020 and 2030 and show how distributed cogeneration units are flexible and suited to provide balancing power, thereby contributing to the integration of renewable electricity.

In the paper “A methodology for designing flexible multi-generation systems” [29], Lythcke-Jørgensen et al. present a novel, generic methodology for designing FMGs (flexible multi-generation systems) that facilitate quick and reliable pre-feasibility analyses. They document how an FMG may facilitate integration and balancing of fluctuating renewable energy sources in the energy system in a cost- and energy-efficient way, thereby playing an important part in smart energy systems.

In the paper “Case study of the constraints and potential contributions regarding wind curtailment in Northeast China” [30] by Xiong et al., the authors evaluate the potential of technical improvements that could be implemented to increase wind integration in north-east China. The results also indicate that more flexible dispatch rules and integration between the electricity and heating sectors are believed to be a mature technical solution to increase wind integration in northern China.

The next four papers address the importance of low-temperature district heating systems and how to implement these in the transition towards future smart energy systems and solutions.

In the paper “Decentralized substations for low-temperature district heating with no Legionella risk, and low return temperatures” [31], Yang et al. address the concern about Legionella when applying low-temperature district heating in conventional systems with domestic hot water (DHW) circulation.

In the paper “Replacing critical radiators to increase the potential to use low-temperature district heating – a case study of 4 Danish single-family houses from the 1930s” [32], Østergaard and Svendsen evaluate the actual radiator sizes and heating demands in four existing Danish single-family houses from the 1930s. The results indicate that there is great potential for using low-temperature district heating in existing single family houses.

In the paper “System dynamics model analysis of pathway to 4th generation district heating in Latvia” [33], Ziemele et al. investigate the possibility of introducing 4th generation district heating in Latvia based on system dynamic modelling. Results shows that a scenario, in which no policy instruments are used, reduces CO_2 emissions by 58.6% until 2030; however, it is possible to achieve a zero emission level in case policy instruments are used.

In the paper “Low temperature district heating in Austria: Energetic, ecologic and economic comparison of four case studies” [34], Köfinger et al. examine the feasibility of district heating networks for areas with low heat demand of passive and low-energy houses. The results of the study show that the availability and economic conditions of low-temperature heat sources are a key factor in facilitating low-temperature district heating networks. In rural areas, lower heat losses due to lower network temperatures are beneficiary for the low-temperature district heating network performance.

The following four papers focus on the relationship between 4th generation district heating and renewable energy and the use of surplus heat and they show how the transformation towards low-temperature district heating furthers the integration of smart renewable energy solutions.

In the paper “Complex thermal energy conversion systems for efficient use of locally available biomass” [35], Kalina describes a theoretical study in search for new technological solutions in the field of electricity generation from biomass in small-scale distributed cogeneration systems.

In the paper “Current and future prospects for heat recovery from waste in European district heating systems: A literature and data review” [36], Persson and Münster show how a key factor in obtaining the full synergetic benefits of waste energy recovery is the presence of local heat distribution infrastructures, without which no large-scale recovery and utilization of excess heat is possible.

In the paper “Mapping of potential heat sources for heat pumps for district heating in Denmark” [37], Lund and Persson investigate the use of large heat pumps for district heating and show that potential heat sources are present near almost all district heating areas and that sea water most likely will have to play a substantial role as a heat source in future energy systems in Denmark.

In the paper “Industrial Surplus Heat Transportation for Use in District Heating” [38], Chiu et al. explore the use of mobile thermal energy storage for transport of industrial surplus heat for use in low-temperature district heating networks. The results of the study show an array of transport means and storage operating strategies under which such a storage technology is technically, economically and environmentally sound.

The final three papers focus on the need for mapping in planning and designing smart heating and cooling solutions.

The paper "European space cooling demands" [39] by Werner presents a cooling atlas for Europe. The main findings are that (1) the estimated specific cold deliveries are somewhat lower than other estimations based on electricity inputs and assumed performance ratios, (2) aggregated space cooling demands are presented by country, and (3) a European contour map is presented to show average specific space cooling demands for service sector buildings.

The paper "Optimal planning of heat supply systems in urban areas" [40] by Stennikov and Iakimetc focuses on the need to solve problems of planning and presents a complex methodology which allows to define locations of heat sources. The paper concludes that the less value of heat density in the system, the higher specific costs for generation, distribution and transmission of heat energy.

In the paper "Ringkøbing-Skjern in building stock" [41] by Petrović and Karlsson, a GIS-based energy atlas for the municipality of Ringkøbing-Skjern in western Denmark is presented. The paper shows that significant heat saving potential lies in farmhouses and detached houses as well as in buildings built before 1950.

5. Conclusions and remarks

This special issue of the 1st International Conference on Smart Energy Systems and 4th Generation District Heating (SES4DH 2015) presents a number of papers elaborating on or otherwise contributing to the theoretical scientific understanding on how we can design and implement a suitable and least-cost transformation into a sustainable energy future. The concept of Smart Energy Systems emphasizes the importance of being coherent and cross-sectoral when the best solution are to be found and how this also calls for the active inclusion of the heating and cooling sectors. The concept of 4th Generation District Heating emphasizes that district heating and cooling are both important elements but also technologies that have to be developed further into a 4th generation to be able to fulfil their roles in future sustainable energy systems. The conclusion is that further development of such a theoretical scientific understanding is essential for the implementation of political goals related to future sustainable energy solutions.

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References

[1] Lund H, Mathiesen BV, Hvelplund F, Østergaard PA, Christensen P, Connolly D, et al. Coherent Energy and Environmental System Analysis. 2011. Aalborg.
[2] Kwon PS, Østergaard PA. Priority order in using biomass resources – energy systems analyses of future scenarios for Denmark. Energy 2013;63:86–94. http://dx.doi.org/10.1016/j.energy.2013.10.005.
[3] Mathiesen BV, Lund H, Connolly D. Limiting biomass consumption for heating in 100% renewable energy systems. Energy 2012;48:160–8. http://dx.doi.org/10.1016/j.energy.2012.07.063.
[4] Alberg Østergaard P, Mathiesen BV, Möller B, Lund H. A renewable energy scenario for Aalborg municipality based on low-temperature geothermal heat, wind power and biomass. Energy 2010;35:4892–901. http://dx.doi.org/10.1016/j.energy.2010.08.041.
[5] Østergaard PA, Lund H. A renewable energy system in Frederikshavn using low-temperature geothermal energy for district heating. Appl Energy 2011;88:479–87. http://dx.doi.org/10.1016/j.apenergy.2010.03.018.
[6] Lund H, Mathiesen BV. Energy system analysis of 100% renewable energy systems-the case of Denmark in years 2030 and 2050. Energy 2009;34:524–31. http://dx.doi.org/10.1016/j.energy.2008.04.003.
[7] Lund H, Hvelplund F. The economic crisis and sustainable development: The design of job creation strategies by use of concrete institutional economics. Energy 2012;43:192–200.
[8] Lund H, Andersen AN, Østergaard PA, Mathiesen BV, Connolly D. From electricity smart grids to smart energy systems – a market operation based approach and understanding. Energy 2012;42:96–102. http://dx.doi.org/10.1016/j.energy.2012.04.003.
[9] Lund H. Renewable Energy Systems – A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions. 2nd ed. Academic Press; 2014.
[11] Lund H, Mathiesen BV, Connolly D, Østergaard PA. Renewable energy systems – a smart energy systems approach to the choice and modelling of 100 % renewable solutions. Chem Eng Trans 2014;39:1–6. http://dx.doi.org/10.3303/CET1439001.
[12] Lund H, Thellufsen JZ, Aggerholm S, Wichtten KB, Nielsen S, Mathiesen BV, et al. Heat saving strategies in sustainable smart energy systems. Int J Sustain Energy Plan Manag 2014;04:3–16.
[13] Mathiesen BV, Lund H, Connolly D, Wenzel H, Østergaard PA, Möller B, et al. Smart energy systems for coherent 100% renewable energy and transport solutions. Appl Energy 2015;145:139–54. http://dx.doi.org/10.1016/j.apenergy.2015.01.075.
[14] Connolly D, Lund H, Mathiesen BV. Smart energy Europe: the technical and economic impact of one potential 100% renewable energy scenario for the European Union. Renew Sustain Energy Rev 2016;60:1634–53. http://dx.doi.org/10.1016/j.rser.2016.02.025.
[15] Kwon PS, Østergaard P. Assessment and evaluation of flexible demand in a Danish future energy scenario. Appl Energy 2014;134:309–20. http://dx.doi.org/10.1016/j.apenergy.2014.08.044.
[16] Lund H, Werner S, Wiltshire R, Svendsen S, Thorsen JE, Hvelplund F, et al. 4th Generation District Heating (4GDH). Integrating smart thermal grids into future sustainable energy systems. Energy 2014;68:1–11. http://dx.doi.org/10.1016/j.energy.2014.02.089.
[17] Lund H, Möller B, Mathiesen BV, Dyrelund A. The role of district heating in future renewable energy systems. Energy 2010;35:1381–90. http://dx.doi.org/10.1016/j.energy.2009.11.023.
[18] Möller B, Lund H. Conversion of individual natural gas to district heating: Geographical studies of supply costs and consequences for the Danish energy system. Appl Energy 2010;87:1846–57.
[19] Connolly D, Lund H, Mathiesen BV, Werner S, Möller B, Persson U, et al. Heat roadmap Europe: combining district heating with heat savings to decarbonise the EU energy system. Energy Policy 2014;65:475–89. http://dx.doi.org/10.1016/j.enpol.2013.10.035.
[20] Persson U, Möller B, Werner S. Heat Roadmap Europe: Identifying strategic heat synergy regions. Energy Policy 2014;74:663–81. http://dx.doi.org/10.1016/j.enpol.2014.07.015.
[21] Hvelplund F. Renewable energy and the need for local energy markets. Energy 2006;31:2293–302. http://dx.doi.org/10.1016/j.energy.2006.01.016.
[22] Chittum A, Østergaard PA. How Danish communal heat planning empowers municipalities and benefits individual consumers. Energy Policy 2014;74:465–74. http://dx.doi.org/10.1016/j.enpol.2014.08.001.
[23] Østergaard PA, Lund H, Mathiesen BV. Smart energy systems and 4th generation district heating. Int J Sustain Energy Plan Manag 2016;10:1–2. http://dx.doi.org/10.5278/ijsepm.2016.10.1.
[24] Büchele R, Kranzl L, Müller A, Hummel M, Hartner M, Deng Y, et al. Comprehensive assessment of the potential for efficient district heating and cooling and for high-efficient cogeneration in Austria. Int J Sustain Energy Plan Manag 2016. http://dx.doi.org/10.5278/ijsepm.2016.10.2.
[25] Prina MG, Cozzini M, Garegnani G, Moser D, Oberegger UF, Vaccaro R, et al. Smart energy systems applied at urban level: the case of the municipality of Bressanone-Brixen. Int J Sustain Energy Plan Manag 2016:10. http://dx.doi.org/10.5278/ijsepm.2016.10.4.
[26] Razani AR, Weidlich I. A genetic algorithm technique to optimize the configuration of heat storage in DH networks. Int J Sustain Energy Plan Manag 2016:10. http://dx.doi.org/10.5278/ijsepm.2016.10.3.
[27] Nastasi B, Lo Basso G. Hydrogen to link heat and electricity in the transition towards future smart energy systems. Energy 2016;110:5–22. http://dx.doi.org/10.1016/j.energy.2016.03.097.
[28] Schüwer D, Krüger C, Merten F, Nebel A. The potential of grid-orientated distributed cogeneration on the minutes reserve market and how changing the operating mode impacts on CO_2 emissions. Energy 2016;110:23–33.

http://dx.doi.org/10.1016/j.energy.2016.02.108.
[29] Lythcke-Jørgensen C, Ensinas AV, Münster M, Haglind F. A methodology for designing flexible multi-generation systems. Energy 2016;110:34–54. http://dx.doi.org/10.1016/j.energy.2016.01.084.
[30] Xiong W, Wang Y, Mathiesen BV, Zhang X. Case study of the constraints and potential contributions regarding wind curtailment in Northeast China. Energy 2016;110:55–64. http://dx.doi.org/10.1016/j.energy.2016.03.093.
[31] Yang X, Li H, Svendsen S. Decentralized substations for low-temperature district heating with no Legionella risk, and low return temperatures. Energy 2016;110:65–74. http://dx.doi.org/10.1016/j.energy.2015.12.073.
[32] Østergaard DS, Svendsen S. Replacing critical radiators to increase the potential to use low-temperature district heating – A case study of 4 Danish single-family houses from the 1930s. Energy 2016;110:75–84. http://dx.doi.org/10.1016/j.energy.2016.03.140.
[33] Ziemele J, Gravelsins A, Blumberga A, Vigants G, Blumberga D. System dynamics model analysis of pathway to 4th generation district heating in Latvia. Energy 2016;110:85–94. http://dx.doi.org/10.1016/j.energy.2015.11.073.
[34] Köfinger M, Basciotti D, Schmidt RR, Meissner E, Doczekal C, Giovannini A. Low temperature district heating in Austria: energetic, ecologic and economic comparison of four case studies. Energy 2016;110:95–104. http://dx.doi.org/10.1016/j.energy.2015.12.103.
[35] Kalina J. Complex thermal energy conversion systems for efficient use of locally available biomass. Energy 2016;110:105–15. http://dx.doi.org/10.1016/j.energy.2016.02.164.
[36] Persson U, Münster M. Current and future prospects for heat recovery from waste in European district heating systems: a literature and data review. Energy 2016;110:116–28. http://dx.doi.org/10.1016/j.energy.2015.12.074.
[37] Lund R, Persson U. Mapping of potential heat sources for heat pumps for district heating in Denmark. Energy 2016;110:129–38. http://dx.doi.org/10.1016/j.energy.2015.12.127.
[38] Chiu JN, Castro Flores J, Martin V, Lacarrière B. Industrial surplus heat transportation for use in district heating. Energy 2016;110:139–47. http://dx.doi.org/10.1016/j.energy.2016.05.003.
[39] Werner S. European space cooling demands. Energy 2016;110:148–56. http://dx.doi.org/10.1016/j.energy.2015.11.028.
[40] Stennikov VA, Iakimetc EE. Optimal planning of heat supply systems in urban areas. Energy 2016;110:157–65. http://dx.doi.org/10.1016/j.energy.2016.02.060.
[41] Petrović S, Karlsson K. Ringkøbing-Skjern energy atlas for analysis of heat saving potentials in building stock. Energy 2016;110:166–77. http://dx.doi.org/10.1016/j.energy.2016.04.046.

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