International Journal of Energy, Information and Communications
Vol.5, Issue 1 (2014), pp.21-32
http://dx.doi.org/10.14257/ijeic.2014.5.1.03

The Benefits of Combined District Energy Modelling and Monitoring: the Case of District Heating

Pierrick Bouffaron[1] and Andreas Koch[2]

[1] *Science & Technology Office, Consulate General of France, San Francisco, USA*
[2] *European Institute for Energy Research, Karlsruhe, Germany*

pierrick.bouffaron@mines-paris.org, koch@eifer.org

Abstract

Urban areas represent sensitive centres of energy use: the district scale notably appears highly suitable for the implementation of energy management strategies. Recently smart metering and monitoring applied to electrical grids have been drawing the full attention of the scientific community. This is insufficient: the monitoring-based approach should address the complete set of energy sources, carriers and conversion points, including district heating systems. However, the deployment of IT-equipped energy networks raises economic and regulatory issues that must be evaluated, including the competitiveness of ubiquitous monitoring and the creation of new end-user pricing structures. Modern energy policies are expected to face this evolution. This paper argues that direct and indirect benefits of monitoring policies for district energy systems are numerous. The necessity to consider both modelling and monitoring during project implementation is stressed: technical, economic and environmental aspects of district energy systems are considered and help identify possibilities for future studies.

Keywords: *monitoring, modelling, district heating, smart network, energy policy*

1. Introduction

Most western countries are facing the challenge of reducing energy use and the associated greenhouse gas emissions in all sectors of their economy [1]. Over the last decade, the relationship between environmental degradation, social and economic inefficiency on the one hand, and unsustainable production and consumption patterns on the other has been stressed. Future energy supplies will face the accelerating depletion of natural resources coupled with the necessity to cope with climate and more broadly environmental changes: failures by city planners to ensure the basis for adequate energy supply infrastructure will have tremendous negative impacts on local economies and the environment. Innovation and integration are going to play a fundamental role in tackling this challenge: the development of all infrastructures must reflect this thinking. Without serious upgrading of existing networks and metering infrastructure, increased generation from renewable sources and adopted energy markets changes will occur at a much slower pace than current scenarios deem necessary (see [2]). From buildings to cities, comprehensive model frameworks turn out to be highly necessary to anticipate the technical, economic and social impacts of adopting new technologies and energy policies. In this paradigm, districts represent a favorable development scale for the planning, modelling and implementation of energy management strategies [3-4]. A great deal of modelling techniques is born from the necessity to face these relatively new requirements of designing sustainable and low-energy urban networks [5].

ISSN: 2093-9655 IJEIC

Stakeholders may have diverse motivations when launching district energy management: the modelling orientation shall be positioned at the intersection of these requirements. The selected modelling tool is theoretically enough flexible to allow defining and illustrating each actor's own concerns [6].

This paper offers an analysis of the couple modelling-monitoring on a district level, emphasizing the benefits of integrating long-term monitoring approaches based upon on-site measurements. Measures fuel the forecast energy models to challenge the expected values, thus modelling and monitoring are two sides of the same coin and are stressed as inseparable assets, especially during decision-making process. The monitoring concept has initiated a change of thinking and represents a progression from traditional design where medium and long-term impacts of energy networks were too often put aside: quality control of energy systems has slowly moved toward quality management. This evolution follows the framework set out in current European environmental and sustainable policies which foster the increase of eco-efficiency and identify all activities, tools, policies and mechanisms for tracking progress and energy consumption levels in urban areas [7]. It also follows in the footsteps of previous works regarding community energy management, a notion defined as the combination of planning and energy management concepts, involving integrated resource planning and demand-side management approaches [8]. This paper especially focuses on the potential of monitored district heating systems. Heat represents a major fraction of modern society's energy needs: the installation or upgrading of district heating systems with advanced and integrated solutions has the potential to reduce energy use and environmental pollution [9-10].

2. District Energy Modelling

2.1. District energy networks

A district energy network is a concept built around the assumption of a cluster of electrical and thermal loads together with small, or at least decentralized, sources of electrical power and heat. Power sources are most of the time mixed, including renewable sources such as photovoltaic or wind generators together with fossil fuel generators or storage units meeting local heating requirements and/or generating electricity. District energy involves multi-building power generation, heating and cooling, in which heat and/or cold is distributed by circulating hot water or low-pressure steam through underground piping [11-14].

Existing and future district energy systems will have to be efficient and cost-effective to be competitive on deregulated energy markets which are becoming nationally and internationally integrated [15-18]. One of the strong benefits of the district approach is to enhance more imaginative schemes for meeting the local energy demand in a flexible manner with the available potential of small scale generation while considering consumer behavior. Therefore district energy planning requires a precise assessment of current district energy needs and their probable development over time. Design and optimization processes account for several successive stages: selection of the most efficient technologies, optimal configuration involving the definition of all components and interconnections, details of operating flow rates, pressures and temperatures of the working fluids for heating and cooling networks, and finally calculation of dynamic optimal operating points [19]. Following these initial phases, a maintenance and operational plan is commonly set up.

2.2. Urban energy modelling

When getting into modelling, the scale of the district is to be considered carefully. Traditional modelling methods range from the building scale – mostly described following a forward approach, a physical representation of the energy fluxes – to the city, predominantly modelled following data-driven techniques, and based upon statistical data sets. The calculation of district loads is often translated into the former, which means a generalized physical description of the district systems that incorporates losses in the distribution and auxiliary sources. Today intermediate methods such as grey-box approaches are being developed at the crossroads between forward and statistic models [20-21].

Using this plurality of design philosophies, energy modelling has been and still is the most basic approach in aiding energy planners. The major ambition of energy models is to create efficient tools for decision support and policy making, which require a precise set of assumptions and rules, depending on the exact purpose of the project. Models are used to represent, simulate and reveal what could be weaknesses in a project or identify opportunities before implementation. They can reveal unexpected facets of a combination of systems, or later highlight divergences between initially modelled load curves, real site and optimized consumption patterns. Therefore this paper puts forward the argument that monitoring is an additional asset to the modelling, and should be integrated into the general project structure. Challenging modelling forecasts with on-site measurements helps to optimize the demand-side load management and subsequently also the forecasting capabilities of the model used.

3. The Monitoring Approach

3.1. The complexity of modern energy management

Urban planners are fully aware of the complexity inherent to energy management scenarios. Consequently cities start responding in the form of local and adapted strategies that encompass a wide range of stakeholders, actors and sectors. Thus, the large number of characteristics used to define district energy use patterns spans from technical and economic to social and environmental dimensions, each of which requiring a specific analysis within the necessary process of data management. For instance, in the deregulated energy markets, even when energy planners are private companies that make investment and business decisions, they are still constrained by social, regulatory and political issues [22]. In the short-term, they face the requirements imposed by the restructuration of a fast-evolving and deregulated energy sector, while in the medium and long-term, they are now expected to take sustainable measures and add other criteria that are harder to monetize. This is a dramatic and welcomed evolution, since district planning approaches have traditionally focused on technical and economic aspects and have neglected environmental, social and political concerns. Therefore planning and monitoring take place at three different levels, that is to say operative, tactical and strategic: operative while targeting high-efficiency facilities, tactical when trying to protect the interests of all involved players, and strategic while having mid and long-term perspectives.

3.2. Technical and non-technical dimensions of monitoring

The concept of monitoring on a district scale underlines the growing will of energy-optimized networks and durable processes. Monitoring networks implemented on top of physical architectures are considered to be real assets and should be both implemented and regulated: challenging modelling forecasts with on-site measurements during operation strongly helps optimize the demand-side load management. The additional communication-based monitoring architecture is designed in such a way that all network players have the possibility to interact at any time and in all directions [23-24]. Once again, this is all about information. Information is necessary for all energy actors, most especially utilities and regulators, to provide a framework for a competitive market and ensure the constant efficiency of district energy systems, paving the way for more cost-effectiveness.

Monitoring is to be considered during initial project stages with the aim to validate the final achievements and document the design calculations. Baedeker [25] made clear that any measurement system dealing with quantitative aspects produce reliable results and point out a direction towards sustainability when combined with an assessment system which will also include qualitative data. In other words, the production of integrated results is dependent on strategies combining measures and evaluation. The ‘best’ district energy network would be that satisfying a criterion of optimality, which mathematically boils down to finding the optimal conditions which give the extremum of an objective function of the overall operation system. This simplified overview should not conceal the challenge inherent to the definition of the function itself, which contains all the variables contributing to the system performance. In the case of district energy networks, the function may be defined as the aggregated global cost relative to demand, or focusing upon reliability, efficiency and environmental impacts. In light of the multiplicity of potential project objectives and linked sets of indicators, a resolution framework is to be decided on a case-by-case basis, following the initial conditions set out of the study.

The added value of installing communication architectures lies also in the multiplication of multi-usage experiments integrating monitoring that will generate the production of large amounts of data and improve future post-analysis and decision-making processes. The mid-term result will be a more useful and reliable information for use by planners and energy utilities. This is especially important when regulators compare the obtained data with business models of utilities to design an appropriate redistribution scheme and global policy [26]. New policies should stipulate the gains involved for each actor in order to redistribute accordingly the regulation-induced revenue [27], districts represent an intermediary scale in-between buildings and cities, two distinct scales which have been traditionally studied respectively through physical and data-driven representations. While new models combining statistic and forward strategies are developed to overcome the difficulties inherent to the intermediate scale, the potential of monitoring in helping plan load schedules and future design is preponderant. Therefore monitoring of district energy networks is to be built on two complementary pillars: on one hand the technical dimension, dealing with the selected technologies and energy flow paths - including the availability of the energy resources, the evolution of demand for the different involved end-use energy types or the control of technologies regarding energy conversion, transport or storage; on the other hand, the decision-making dimension, considering the economic and societal impacts, the influence of systems on the environment and the political and social implications.

3.3. The example of smart electric grids

Monitoring approaches for electric grids are largely developed, attracting the attention of the scientific community and public authorities. Smart grids can be defined in several ways and involve a large range of technologies. The European Union[1] defines them as “electricity networks that can intelligently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies”. The US Department of Energy adds the capacity of “self-healing from power disturbance events, operating resiliently against physical and cyber-attack, accommodating all generation and storage options and optimizing assets and operating efficiently.”

Most European countries are today involved in smart grid pilot projects. The implementation and application of Information and Communication Technologies (ICTs) intervenes at different levels of the power value chain, targeting generation, transmission and distribution grids, smart metering and finally intelligent buildings. At plant level, monitoring devices measure power outputs and consumptions in real time, sending data back and forth to the electrical network manager and the customers. Monitored distribution grids come along with demand-side management strategies which help grid operators anticipate the load schedules and ensure the network stability, entailing adapted pricing schemes. At residential levels, the installed smart meters allow the regular reading, processing and feedback of consumption data to the customer [28]. Today demand response by domestic energy users is not yet a spread practice. However, when all buildings and national companies are able to adapt their energy consumption on demand, the reliability of supply, the stability of the upstream (production) and downstream (consumption) markets, the customer awareness and the global network efficiency will be enhanced. The benefits of electricity grid monitoring would thus contribute to the planned energy goals of national governments and foster the elaboration and application of climate protection policies [29].

4. District Heating: a Technical Perspective

4.1. District heating networks

The control of district heating systems is a complex task, since production and distribution are characterized with a considerable response delay mainly due to the size of the distribution network [30]. In order to face this problem of inertia and non-linearity of the system behavior, planning the production and distribution so that customers are constantly supplied is a necessity. The simplified architecture of district heating networks is generally built around key elements: one (or several) central plant(s) producing the necessary amount of heat to meet the demand, potential heat stores, a complex underground piping network and substations embedded within the network which represent one - or a set of - customer(s).

Originally designed as independent technologies, each substation generally tries to satisfy the demands of its downstream customers without taking into account the rest of the network. Therefore a district heating network is a collection of autonomous entities, resulting in a behavior which is only optimized locally. Any shortage of the systems would for instance favor the customers close to the plant. In the meantime, the plant operator does not have much information concerning the state of the network. This together with the high distribution time results in that the heat production is roughly estimated by the operators, who often waste energy to ensure sufficient and continuous heat supply [31]. The problem is highly dynamic and frequent decisions and selections have to be made to run properly the system and minimize costs: it can include, for

---

[1] http://www.smartgrids.eu

instance, the amounts of heat to be produced by the various embedded plants, water temperature levels to set up or pumps to be started and stopped.

4.2. The monitoring architecture

The first interest of monitoring for district heating is to add controllers and sensors that make it possible to reduce surplus production by increasing the knowledge about the current and future state of the global system: monitoring thus relies on the penetration of ICTs. These equipments have been rapidly developed in terms of affordability and availability, new competitors and players continuously fostering the inherent research and development, proposing innovative services and solutions at all levels of the power value chain [23]. The added value of ICT applied to district heating networks is multifold. Operators are mostly interested in the ability of equipped networks to adapt rapidly to meet ongoing information requirements, the autonomous processing of repetitive tasks and the flexibility offered to utilities and users to get information through constant connection services [31-32]. Processes of networks optimization are performed at the crossroads of data measurement and suitable simulation models. Methods and strategies are determined to detect the optimum operation point on the basis of the initial mathematical descriptions and the future available data. Recently energy planners have been focusing on ways to do so, with a specific attention for the necessity of monitoring at different time and space scales, because changes must be measurable at every required level [21].

However, the available monitoring technologies are costly and should be reduced to the minimum to obtain exploitable and suitable economic results. Engineers and planners shall agree on a balance between necessary amounts of data and budget to invest in the monitoring phase. On one hand, engineers should be able to lose sight of the high-level results precision inherent to detailed physical models when the focus is put on having a broader approximation of the energy consumption of a system. On the other hand, planners do not have to sacrifice a posteriori investments with aim to cut immediate costs when monitoring allows reducing networks consumption in a long-term perspective. Therefore the monitoring program must be defined based on the expected customers' needs, and the performance specifications of the installed systems determined accordingly.

Three distinct stages are definable, from the initial project development to the operating phase. During the project development, the design of the networks must be checked following the stated energy consumption requirements. The development of performance baselines follows, with the creation of a metering plan based upon the system conditions, the energy performance plans and the required comfort levels. Then, during the implementation of the monitoring equipment, operation and control schedules must be defined. Documents should be proposed and validated by all stakeholders. Finally, during the monitoring phase, the key point is to keep the monitoring phase continuous, providing weekly, monthly and annual energy savings reports and tracking errors and digressions. An overview is given in Figure 1 below. In practice, the implementation of these guidelines is today often compromised by a lack of awareness from involved actors; an incomplete or inappropriate design that does not meet the monitoring phase requirements (insufficient number of control points, lack to human resources to maintain the monitoring equipments running, etc.) or the necessary budget [33-34].

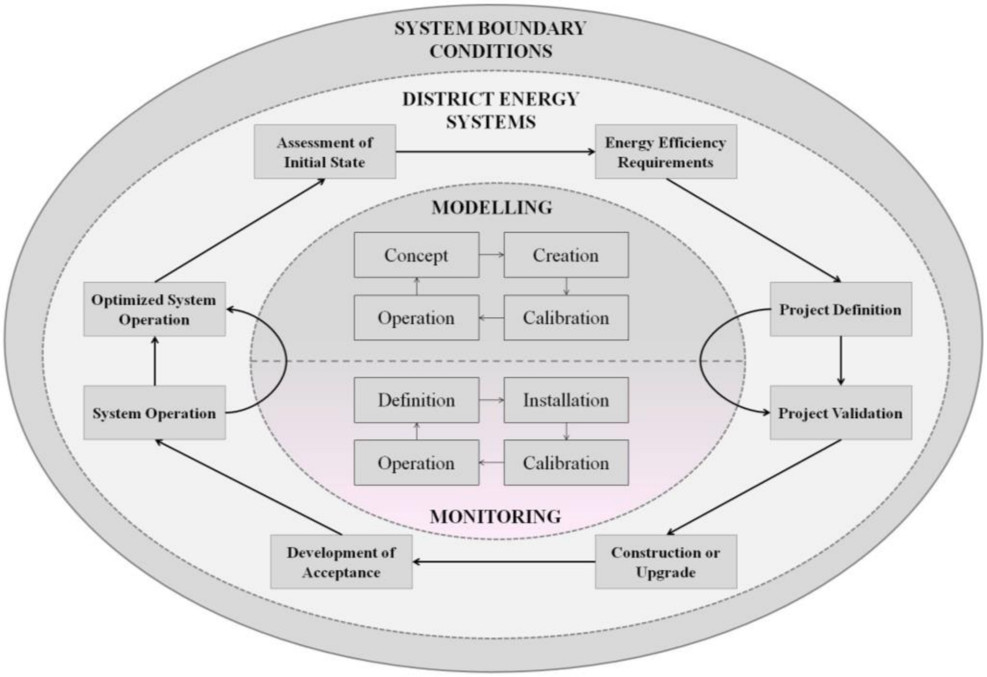

Figure 1. District heating project modelling and monitoring stages

5. District Heating: Non-technical Dimensions

5.1. Economic benefits

The benefits attributed to monitoring are numerous. One of the key direct benefits for the consumer is the cost saving achieved by reducing demand and the possibilities to shift his individual consumption to off-peak periods. In parallel, energy utilities will chase savings on production costs and substantial balancing during periods of high demand [27]. While the enhancement of market stability and robustness is often stressed, others direct advantages exist such as expanded product and service offerings, more accurate bills, avoiding capacity, more equitable and fair rates, improvement of customer satisfaction, conservation effect on energy usage from direct feedback, modernization of the district heating industry and accelerating the adoption of more efficient systems [26, 35-36]. The fitting of ICTs on top of the physical heating architecture means that data on failures or outages are more easily available and prone to analysis, leading to an enhanced precision during reparation and better future outage anticipation. Also, thermal losses can be measured accurately and dealt accordingly. Monitoring will not only improve reaching the efficiency targets, but also the safety of the infrastructure through facilitated maintenance, supervision and work on the heat networks. Development of smarter district heating grids is therefore expected to bring new opportunities all over the heat value chain: the final objective is an integrated information and communication infrastructure where all processes run automatically and information flow between actors is facilitated.

Local planning strategies such as district heating are simultaneously supportive of larger objectives including improved sustainability, accessibility of services and general improvements to urban livability: some of them are non-immediate or intangible nonmonetized benefits. Although the added value of optimized district technologies may somehow be implicit, it does have a tremendous impact on markets. For instance, a faster restoration from a service outage leading to more robust demand response behavior is a key element of district heating financial success and market development. Also, monitoring allows regulators to monitor efficiency levels and accordingly structure incentive schemes inherent to networks performance. Besides, the expanded service choices enabled by metering and communication technology are essential if consumers are to realize the potential benefits of the wholesale competition. A comprehensive framework is thus necessary to evaluate and distinguish benefits sources that can be traced back to utility cost savings from those that result from indirect or secondary impacts on consumers [35]. Economic profit as a result of monitoring can be expected in the mid-term at best when the operators succeed in developing new additional functions and services for which the customer feels a real need and for which he is willing to pay [31].

5.2. Communication, cooperation and stakeholder engagement

Key to the development and implementation of integrated monitoring systems are communication, cooperation and dialogue. This pioneering approach in a traditionally technical field intends to gather actors from policy, production and consumption fields. Constraints are logically expected to be faced; the most relevant political instruments are thereby to be considered to support the effort locally. Suitable regulation and guidelines must then be developed to ensure the transparency and credibility of the monitored district heating networks, and promote a straight-forward, coherent and informed planning process. Importantly, these guidelines must be built upon the three fields of sustainability – ecological, social and economic – and defined according to criteria revealing the project value chain in its entirety. Stress must be put on fostering communication with the public to ensure that project costs and benefits are perfectly understood, and engage all actors in an early debate about project outcomes.

Some of the perceived benefits of district energy management are based on the technical and economic life cycle cost analysis for providing energy supply. However, there may be strong differences in the values society perceives from the alternative technologies to be installed. Integrated management systems at larger scales, including districts, are more likely to offer various benefits to individuals and society as a whole, but the key challenge will be to present these advantages to the greatest number, and make them accept. Communication on the benefits of smarter networks for consumers and citizens, in terms of security of supply, decarbonisation of the energy sector and energy efficiency should be core to local policies of acceptability [37]. However the environmental argument should be considered carefully by investors and regulators to not ignore the economic viability and thus reproducibility of the projects.

The monitoring concept should also account for future trends and developments that may influence consumption and production, such as globalization, the development of the information and knowledge-based society, structural change of employment, individualization and the change of values. It is clear that gains presented to customers should be first price cuts, although it directly raises the question of precisely forecasting the monitoring infrastructure cost. It is expected that the added value from optimizing the networks and mastering the consumption will counterbalance higher prices due to regulation of and higher security and reliance on the heat systems [38].

5.3. Benchmarking

It is of utmost importance to be capable of assessing complex developments in the current social-policy environment. New policies raise the question of the control of their application. They should ensure that all project phases, and not only design, favor energy efficiency by identifying benchmarks for tracking progress. Effective, transparent and non-misleading tools are to be developed for involved stakeholders and final consumers.

The introduction of benchmarks, notably into developer negotiations, is an example of necessary evolution towards more stakeholders' awareness. The question of benchmarking for district heating is primordial and complex. The traditional design of thermal networks creates natural monopolies where a single supplier is connected with a large range of customers. Rezaie [3] highlighted that such specificity had played a major role to foster the liberalization of other energy markets such as electricity or gas, because trans-areas transmission networks have been able to facilitate their development. Therefore, a good way to ensure fair prices to district heating consumers could be benchmarking. Benchmarking aims at rewarding good performance of energy utilities by measuring efficiency and quality of services set against levels pre-determined by regulators. The interest of benchmarking is twofold [22-39]: on the one hand, the regulated utilities finally enter in an enhanced competitive market, which helps them be up to date regarding modern technologies and organizational know-how. On the other hand, all actors including consumers and regulators are given norms against which they have the possibility to compare the performance of energy utilities. Benchmarks definition and techniques used to measure them are numerous, ranging from the simple key figures, econometrics and DEA models, or between frontier-based and non-frontier-based methods [40]. As a result, it could be proposed that certifications are delivered to energy utilities only if the states of the energy network at different defined periods meet the theoretical initial target values [8, 10, 22].

6. Conclusion

The implementation of district energy strategies follows a three-stage process: initial design phases which require integrated energy models, site implementation and finally network operation involving maintenance and monitoring. Monitoring brings more symmetry to these processes and is expected to improve the network's productive and allocative efficiency. Energy utilities are better positioned to forecast peak periods and propose adapted management measures and dynamic tariffing, which means prices that exactly meets consumers' expectations. While direct and indirect economic impacts of monitoring systems can be strenuous to measure and monetize, they largely contribute to the benefits that consumers and developers realize from monitoring investments. The resulting transparency of actual efficiency levels and the associated benefits could possibly also result in new business models for contracting services. Current projects are expected to exploit synergies between modern objectives of urban development, notably regarding human comfort and security of energy supply, and current targets of reducing energy consumption and cutting greenhouse gas emissions. Multi-scale planning and monitoring requirements are today better described and are increasingly implemented into local policies. This recent move towards integrated energy networks highlights a new holistic approach where design choices are made from a community perspective.

References

[1] V. Arroyo and K. Zyla, "Agenda for climate action", Pew Centre on Global Climate Change, Arlington, VA, **(2006)**.
[2] J. Nitsch, T. Pregger, Y. Scholz, M. Sterner, N. Gerhardt, A. Von Oehsen, C. Pape, Y. M. Saint-Drenan and B. Wenzel, "Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global", Deutsches Zentrum für Luft-und Raumfahrt, Fraunhofer Institut für Windenergie und Energiesystemtechnik, Ingenieurbüro für neue Energien, vol. BMU-FKZ0, **(2010)**.
[3] B. Rezaie and M. A. Rosen, "District heating and cooling: Review of technology and potential enhancements", Applied Energy, vol. 93, **(2012)**, pp. 2-10.
[4] A. Koch, S. Girard and K. McKoen, "Towards a neighbourhood scale for low-or zero-carbon building projects", Building Research & Information, vol. 40, **(2012)**, pp. 527-537.
[5] A. Koch, "Energy balance of urban quarters for the development of energy efficiency and management strategies", Fifth Urban Research Symposium 2009. Marseille, France, **(2009)** June 28-30.
[6] L. G. Swan and V. I. Ugursal, "Modeling of end-uses energy consumption in the residential sector: A review of modeling techniques", Renewable and Sustainable Energy Reviews, vol. 13, no. 8, **(2009)**, pp. 1819–1835.
[7] Commission of the European Communities, "A European strategic energy technology plan: 'Towards a low carbon future'. Communication from the commission to the council, the European parliament, the European economic and social committee and the committee of the regions", **(2007)**, eur-lex.europa.eu.
[8] M. Jaccard, L. Failing and T. Berry, "From equipment to infrastructure: community energy management and greenhouse gas emission reduction", Energy Policy, vol. 25, no. 13, **(1997)**, pp. 1065-1074.
[9] IEA (International Energy Agency), "District heating distribution in areas with low heat demand density", IEA Implementing Agreement on District Heating and Cooling, including the integration of CHP, **(2008)** March.
[10] U. Persson and S. Werner, "Heat distribution and the future competitiveness of district heating", Applied Energy, vol. 88, no. 3, **(2011)**, pp. 568–576.
[11] J. Summerton, "District heating comes to town: the social shaping of an energy system", Linköping. Linköping University Press, **(1992)**.
[12] A. Midilli, I. Dincer and M. Ay, "Green energy strategies for sustainable development", Energy Policy, vol. 34, no. 18, **(2005)**, pp. 3623–3633.
[13] M. Marinova, C. Beaudry, A. Taoussi, M. Trépanier and J. Paris, "Economic assessment of rural district heating by bio-steam supplied by a paper mill in Canada", Bulletin of Science, Technology and Society, vol. 28, no. 2, **(2008)**, pp. 159–73.
[14] Y. P. Cai, G. H. Huang, Z. F. Yang and Q. Tan, "Identification of optimal strategies for energy management systems planning under multiple uncertainties", Applied Energy, vol. 86, no. 4, **(2009)**, pp. 480–495.
[15] E. Axelsson, S. Harvey and T. Berntsson, "A tool for creating energy market scenarios for evaluation of investments in energy intensive industry", Energy, vol. 34, no. 7, **(2009)**, pp. 2069–2074.
[16] V. Galvani and A. Plourde, "Portfolio diversification in energy markets", Energy Economics, vol. 32, no. 2, **(2010)**, pp. 257–268.
[17] C. H. Liao, H. H. Ou, S. H. Lo, P. T. Chiueh and Y. H. Yu, "A challenging approach for renewable energy market development", Renewable and Sustainable Energy Reviews, vol. 15, no. 1, **(2011)**, pp. 787–793.
[18] J. Zarnikau, "Successful renewable energy development in a competitive electricity market: A Texas case study", Energy Policy, vol. 39, no. 7, **(2011)**, pp. 3906–3913.
[19] C. A. Frangopoulos, M. R. Von Spakovsky and E. Sciubba, "A brief review of methods for the design and synthesis optimization of energy systems", International Journal of Applied Thermodynamics, vol. 5, no. 4, **(2002)**, pp. 151-160.
[20] H. A. Nielsen and H. Madsen, "Modelling the heat consumption in district heating systems using a grey-box approach", Energy and Buildings, vol. 38, no. 1, **(2006)**, pp. 63–71.
[21] A. Koch, "Heat Demand Modeling at the Scale of Urban Neighborhoods", Next Generation Infrastructure Systems for Eco-cities Conference, Shenzhen, China, **(2010)**.

[22] J. Agrell and P. Bogetoft, “Economic and environmental efficiency of district heating plants”, Energy Policy, vol. 33, no. 10, **(2005)**, pp. 1351-1362.

[23] M. Wissner, “The Smart Grid – A saucerful of secrets?”, Applied Energy, vol. 88, no. 7, **(2011)**, pp. 2509–2518.

[24] J. Gao, Y. Xiao, J. Liu, W. Liang and C. L. P. Chen, “A survey of communication/networking in Smart Grids”, Future Generation Computer Systems, vol. 28, no. 2, **(2012)**, pp. 391-404.

[25] C. Baedeker, C. Liedtke and M. J. Welfens, “Analysis of existing concepts for measuring sustainable consumption in Germany and main features of a development concept”, Final report, Wuppertal Institute for Climate, Energy and Environment, **(2007)**.

[26] C. Clastres, “Smart grids: Another step towards competition, energy security and climate change objectives”, Energy Policy, vol. 39, no. 9, **(2011)**, pp. 5399–5408.

[27] P. Fox-Penner, “Smart Power: Climate Change, the Smart Grid, and the Future of Electric Utilities”, Island Press, **(2010)**.

[28] W. Qia, J. Liua and P. D. Christofides, “A distributed control framework for smart grid development: Energy/water system optimal operation and electric grid integration”, Journal of Process Control, vol. 21, no. 10, **(2011)**, pp. 1504–1516.

[29] S. S. S. R. Depuru, L. Wang and V. Devabhaktuni, “Smart meters for power grid: Challenges, issues, advantages and status”, Renewable and Sustainable Energy Reviews, vol. 15, no. 6, **(2011)**, pp. 2736– 2742.

[30] L. Dobos and J. Abonyi, “Controller tuning of district heating networks using experiment design techniques”, Energy, vol. 36, no. 8, **(2011)**, pp. 4633–4639.

[31] M. Friedewald and O. Raabe, “Ubiquitous computing: an overview of technology impacts”, Telematics and Informatics, vol. 28, no. 2, **(2011)**, pp. 55–65.

[32] P. Gabriel, M. Bovenschulte, E. Hartmann, W. Groß, H. Strese, K. M. Bayarou, M. Haisch, M. Mattheß, C. Brune, H. Strauss, H. Kelter and R. Oberweis, "Pervasive Computing: Trends and Impacts", SecuMedia, Ingelheim, **(2006)**.

[33] C. Neumann and D. Jacob, “Guidelines for the evaluation of building performance”, Building EQ Tools and methods for linking EPDB and continuous commissioning, Intelligent Energy Europe, **(2008)**.

[34] H. Erhorn, H. Erhorn-Kluttig and J. Reiss, “Leitfaden für Messkonzepte in EnEff:Stadt. Fraunhofer-Institut für Bauphysik”, Durchgeführt im Auftrag des Bundesministeriums für Wirtschaft und Technologie, **(2012)**.

[35] B. Neenan, “Characterizing and Quantifying the Societal Benefits Attributable to Smart Metering Investments”, EPRI, Electric Power Research Institute, Topical report, **(2008)**.

[36] I. J. Pérez-Arriaga, “Regulatory Instruments for Deployment of Clean Energy Technologies”, EUI RSCAS, Loyola de Palacio Programme on Energy Policy, **(2010)**.

[37] European Commission, “European Technology Platform Smart Grids: Strategic Deployment Document for Europe’s Electricity Networks of the Future”, **(2010)**, www.smartgrids.eu.

[38] IEA (International Energy Agency), “World Energy Outlook 2011”, **(2011)**, www.iea.org.

[39] J. Munksgaard, L. L. Pade and P. Fristrup, “Efficiency gains in Danish district heating. Is there anything to learn from benchmarking?”, Energy Policy, vol. 33, no. 15, **(2005)**, pp. 1986–1997.

[40] T. Jamasb and M. Pollitt, “Security of supply and regulation of energy networks”, Energy Policy, vol. 36, no. 12, **(2008)**, pp. 4584–4589.

Authors

Pierrick Bouffaron received a Master of Science from Ecole Centrale de Nantes with a focus on Energy and Environment (2008) and a Master of Advanced Studies in Economics from Mines ParisTech (2012), with a dissertation in the field of smart power grids. He is currently working at the Consulate general of France in San Francisco, in charge of promoting the French Science & Technology with US actors and watching scientific breakthroughs, investments and innovations in the Bay Area. He has worked in South-East Asia, Australia, Germany, France and the United-States for the last five years.

Mr. Bouffaron has experience in energy production and distribution, renewable energy, global energy and sustainable development issues.

Andreas Koch graduated in Architecture at Technical University of Berlin (2000), received a Master of Science in City Design and Social Science from the London School of Economics (2002) and a Master of Science in Energy Management from Universität Koblenz-Landau (2011). He has several years of professional experience as an architect (Switzerland, Germany) and as a research engineer in Urban Systems at the European Institute for Energy Research (EIFER) in Germany. He is currently the Head of the *Energy Planning and Geosimulation Department* at EIFER. His areas of expertise include energy planning, urban energy systems and energy markets**.**