Energy networks interoperability as a key to increased sustainability in cities

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1. Abstract

A large number of projects aim at moving cities or territories towards a more sustainable future, the latter being measured by a series of energy-related, environmental, social and economic indicators. IntegrCiTy project will bring a contribution to increased sustainability in urban areas by first exploring and successively exploiting the possible synergies among the energy networks in urban areas. This approach has several consequences in terms of sustainability. While interoperability of energy supply networks will undoubtedly allow increased energy efficiency (e.g. by favoring co-generation-based scenarios) and reduced emissions (e.g. by representing a more rational route than oil-based heating), it will at the same time ensure a decrease of investment costs (i.e. moving towards more economic sustainability). In this sense, IntegrCiTy project will shape common ground, first among different energy sectors, second among local stakeholders on a given territory (e.g. industrial companies or residential associations) and, third, at the very political level since interoperability certainly contributes to moving the urban system towards more robustness by increasing the energy supply security.

2. Smartcities and the need for a new approach to energy networks

Worldwide energy challenges have led to the definition of major common objectives addressing local to global levels, such as energy efficiency promotion, optimal use of local and renewable energy resources, as well as greenhouse gas emissions reduction, while keeping the current logic of general economic growth.

The solutions that allow achieving these objectives within a territory are linked to energy demand reduction, equipment and energy conversion systems' efficiency improvement along with a sustained penetration of renewable energies. On top of a more rational and efficient energy use, the whole energy system in itself, from resources extraction to final energy delivery, contains significant potential in terms of both energy savings and use of renewables.

Shifting the present energy paradigm and designing energy systems based on their efficiency and ability to valorize local energy resources, e.g. at urban scale, nonetheless leads to an increased complexity of possible technology-based solutions. The main issues to be faced are related, on one hand, to resources and needs spatial disparity and, on the other hand, to non-simultaneous demand and production. The impact will be even larger due to the increasing number of decentralized (mostly non-dispatchable) production systems and the foreseen changes in consumers' behavior. The spatial-temporal resolution for running energy systems induces new technical challenges which massively affect local energy distribution infrastructures. Typically, in the future, some energy networks may cover more peak and backup demand than baseload energy services. These new supply networks operating modes, induced by more sustainable energy production, will call for large infrastructure investments. The latter will aim at making the supply system more sustainable, robust, less expensive to operate and, if possible, a generator of new income. Owners and operators of these infrastructures will have to choose the more appropriate technological solutions, depending on each specific territory. Energy utilities and city planners will need to compare different solutions, such as designing or extending a district heating network, strengthening an electric distribution grid or integrating a local thermal or electric storage.

The challenge and a part of the solution lie in the combination of storage and multi-energy conversion systems [1,2]. This combination allows energy systems to adapt to an increasingly decentralized energy production, interacting with existing networks (natural gas, electricity, heating and cooling). These "smart integrated solutions" for energy management and conversion increase interoperability capabilities between different energy vectors and open opportunities to develop additional, innovative services to the one based on existing infrastructures and related supply structures. On the supply side, energy networks need to be designed in an integrated way, in order to take advantage of their respective properties and dynamics, as well as to be able to include decentralized production (e.g. PV or co-generation) and renewable gas injection, stemming either from waste or wood methanation processes or, in the near future, from power-to-gas plants.

Finally, integrated solutions and interoperability of energy networks will also become increasingly preferred because they intrinsically lead to avoiding over-dimensioning and thus will be able to provide a first step in investments optimization strategies.

3. Contribution of IntegrCiTy to shaping common ground in urban sustainability

IntegrCiTy project aims at developing and implementing a modular decision-support platform focusing on planning and designing integrated energy networks and further infrastructure developments (extensions, new deployments, retrofitting) [3-5] through multi-energy/networks co-simulation [6,7]. Added value of this modelling and simulation environment will consist in the ability to evaluate every energy aspect in an integrated, simultaneous and spatial approach: demand profiles, resources, supply infrastructure, storage and conversion technologies, along with territorial constraints. Networks study will have three phases: (i) gathering, validating and spatializing all relevant network data [8,9]; (ii) investigating extension and/or retrofitting potential in a given urban zone, including the future development of energy demand and other interfaces [10]; (iii) identifying bottlenecks and opportunities, in particular regarding integration with other energy networks.

The project aims at providing a platform to predict the effects of selected measures (scenarios) for existing or future energy infrastructures. It will therewith be possible to demonstrate that these scenarios - either manually chosen or stemming out of an optimization approach - will help shaping energy demand and supply dynamics in a way as to increase resilience and efficiency of urban energy systems. In particular, the impact of scenarios affecting district heating/cooling (DHC) and natural gas (NG) - i.e. thermal - networks on electricity distribution grids will be quantitatively and spatially modelled for urban districts as test cases, used for validation, as well as model calibration..

As of today, no known platform/tool allows applying this integrated perspective for energy networks. Firstly, IntegrCiTy platform will enable the understanding of each network mechanism. It will anticipate the impact of a new energy system upon the already existing ones. Secondly, IntegrCiTy will identify potential complementarities between multiple energy infrastructures. This requires the simulation of new configurations' impacts on existing networks. Finally, the tool will determine which prospective model is the most efficient (according to selected indicators), how it can meet future demand, takes best advantage of resources, is cost-effective and promotes inter-operability of existing /new infrastructures.

The further goal of this tool is to provide the decision-making process with adequate support in order to improve energy networks profitability in the context of reduced pro-capita and pro-building energy consumption (in industrialized countries), while guaranteeing a reliable and robust energy supply system.

By its core structure allowing multiple tools combination, IntegrCiTy modular decision-support environment will be built to facilitate integration - as to stay updated to current urban metabolism - of future additional features/functionalities, such as improved technologies models, specific structure design or operating strategies optimization tools, refined energy demand estimations, automatic data import interface or even a dedicated H_2 network module.

For energy utilities, such a simulation platform will allow simultaneous evaluation and comparison of different solutions, different by nature (rational use, production, energy distribution and storage), putting them in competition, comparing their global performances in a coherent and transparent manner at territorial scale [3,5,10,11]. IntegrCiTy will bring support upon considering conflicting use of resources and/or infrastructures, which cannot be achieved using non-integrated available tools. IntegrCiTy decision-support tool can be directly used to simulate networks load shifting solutions, to optimize the integrated design of energy systems and for establishing multiannual investment plans. Indeed, an integrated approach allows designing the most adequate and profitable energy system with respect to global demand and to interact with other network infrastructure, while optimizing the use of existing resources. Without such an approach, the system comprehension may not be sufficient as to explore neither synergy opportunities between networks, nor alternative options. Inherent risks are then:

- Realizing non-optimal investments to spread and/or densify urban energy networks (e.g. reinforcing electric networks to accommodate massive injection renewable production) when alternative and profitable options could be available;
- Insufficient integration of renewable resources, or integration without cost optimization;
- Non-durable or optimal use of existing infrastructure;
- Inadequate decision-making regarding new urban energy systems, from both a technological and final customer pricing points of view.

An integrated approach is indeed necessary to include inter-network synergies in decision-making processes. However, utility engineers lack the necessary tools and methods to conduct cost-effective and quantitative analyses in the field.

For city planners, access to comprehensive and structured energy data at an urban territory scale, to be shared with the local stakeholders, will open the door towards creating a "Smart City". First, access to these data will enable to identify and characterize territorial energy uses at different scales. It thus represents an exceptional diagnostic tool for local energy and climate policies implementation. Secondly, by way of collaborations between city administration departments (energy, mobility, environment, spatial planning) and energy utilities, such a decision-making environment will allow refining energy and climate policies programs and to arbitrate investments in different project opportunities. Third, access to these geospatial data will support urban development in its broad sense, with the goal of determining future urban planning according not only with respect to transport axes criteria but also according to energy infrastructures criteria or energy resources availability (renewables including synthetic gases, thermal waste energy, waste materials): new building zones, energy-intensive units implantation, plants with waste heat potential (e.g. data centers, chemical production sites, waste water treatment plants, municipal incinerators).

4. Conclusions and perspectives

The EU needs to accelerate innovation in cutting edge low-carbon technologies and innovative solutions, as well as bridge the gap between research and the market. IntegrCiTy project will bring a contribution towards these objectives fourfold:

1. An integrated urban infrastructure simulation platform will be developed and eventually applied as decision-support environment;
2. Selected scenarios carried out by the tool for districts in partner cities shall be implemented by the respective local energy utilities;
3. Energy networks allow implementing more efficient conversion technologies, as well as renewables (e.g. geothermal, waste or biogas), thus allowing attaining EU's ambitious objectives in terms of long-term energy sustainability;
4. A multi-stakeholder collaboration will be established, including academic institutions, city- and region-level energy authorities, multi-energy utilities, along with an innovative equipment manufacturer and a software start-up company.

The energy infrastructure addressed will make use of low-carbon technologies such as PV and heat pumps, while distributing the energy - power, heat and cooling - through smart grids and district heating networks, to be extended to supply new areas in a low carbon approach.

The approach of the urban infrastructure simulation platform IntegrCiTy project is centered on the notion of interoperability between energy networks and on the integration of energy demand and supply dynamics. The decision-support environment will thus allow evaluating selected or optimized scenarios and compute the respective set of relevant indicators – on energy, environment and land-use aspects –, in a comprehensive, spatialized way and through a systemic approach by use of integrated modelling and co-simulation. Such a broad insight, which will go beyond the standard single energy carrier models, shall precisely evaluate the effects of infrastructure investments and planned policies for alternative low-carbon energy supply. Complexity of the urban energy infrastructure, emergence of decentralized energy sources (such as PV), defining load shifting strategies, the need to rationalize investments in networks developments, increased penetration of electric vehicles, as well as general trend towards more sustainable policies, all naturally call for a holistic approach such as proposed in IntegrCiTy, which will make existing tools and methods work together for the monitoring and management of a selection of urban issues (environmental impact, land use, electric vehicles penetration, buildings, water management and waste valorization).

Moreover, by realizing three implementation test-cases in Stockholm, Vevey and Geneva, IntegrCiTy project will be able to measure the appropriateness and applicability of the decision-support environment, in close collaboration with city administrations and energy utilities, who are the primary beneficiaries of such a tool. The test-cases will also involve other local stakeholders, such as non-energy companies operating in the selected districts or citizen organizations, who will certainly be interested in new energy services and contracting. Social acceptance should be increased by appropriate broad information; in that sense, our spatial explicit modelling approach will facilitate communication with local actors at all levels and create the way to finding a common language, clear also to non-specialists.

Finally, IntegrCiTy will bring an important contribution to the emergence of smart cities, by setting different pieces of the urban energy system in communication and mutual interaction. This tool-box will naturally integrate and put forward more efficient energy conversion technologies/infrastructures; its architecture, based on modelling libraries and interfaces between existing tools, should be perennial and adaptable to future needs.

Shaping common ground in urban sustainability thus indeed represents the philosophical backbone of a project such as IntegrCiTy. This endeavor ambitions to bring together different sectors of the energy sectors and local authorities, around the idea that finding synergies among the energy supply networks and technologies is key to increased energy efficiency.

5. References

[1] J. Keirstead, N. Samsatli, N. Shah, C. Weber, The impact of CHP (combined eat and power) planning restrictions on the efficiency of urban energy systems, Energy: The Iternational Journal 41 (1), (2012) 93-103

[2] T. Noh, D. Schwabeneder, S. Nicolas, M. Schwarz, A. Schuelke, H. Auer, An Investigation Process for Hybrid Energy Grid Optimization, 5th International Conference on Smart Cities and Green ICT Systems, SmartGreens 2016, Rome (Italy), 23-25 April 2016

[3] C. I. Weber, D. Favrat and F. Maréchal (Dirs.). Multi-objective design and optimization of district energy systems including polygeneration energy conversion technologies. PhD Thesis EPFL, n°4018 (2008), Chapter 4.

[4] S. Fazlollahi, F. Maréchal (Dir.). Decomposition optimization strategy for the design and operation of district energy systems. PhD Thesis EPFL, n°6130 (2014).

[5] S. Moret, M. Bierlaire and F. Maréchal. Robust optimization for strategic energy planning. 1st European Conference on Stochastic Programming and Energy Applications (EuroCSP2014), Paris (France), September 2014.

[6] P.Palensky, E. Widl, A. Elsheikh, Simulating cyberphysical energy systems: Challenges, tools and methods, IEEE Transactions on Systems, Man, and Cybernetics: Systems 44 (3) (2014) 318-326.

[7] E. Widl, W. Müller, D. Basciotti, S. Henein, S. Hauer and K. Eder, "Simulation of multi-domain energy systems based on the functionnal mock-up interface specification", Smart Electric Distribution Systems and Technologies (EDST), 2015 International Symposium, Vienna, 2015, pp. 510-515

[8] G. Blanc, G. Cherix, L. Darmayan. How to plan the desirable development of the energy use and supply of a local territory with the use of GIS tool. 8 th Conference on

Sustainable Development of Energy, Water and Environment Systems, Dubrovnik (Croatia), September 2013.

[9] M. Capezzali, G. Cherix, L. Darmayan, S. Restani, P. Puerto, J. Rager. Evolution of and additional functionalities to the city enery planning platform MEU - Proceedings of the International Gas Union Research Conference (IGRC), Copenhagen (DK), September 2014.

[10] M. Capezzali, G. Cherix. MEU – A cartographic-based web-platform for urban energy management and planning – ESRI International User Conference 2012, San Diego (USA), July 2012.

[11] J. Rager, F. Maréchal, L. Darmayan, G. Cherix. Smart Heat Design: Integration and Optimisation of Solar Thermal Energy and other Resources in District Energy System Design. Proceedings of the 3rd International Solar District Heating Conference, Toulouse (France), June 2015.