ECBCS Annex 49: *Low Exergy Systems for High-Performance Buildings and Communities*

Draft version – internal report

SURVEY OF MODELLING TOOLS FOR DISTRIBUTED GENERATION

Paola Caputo, Building Environment Science and Technology Department, Politecnico di Milano

Massimiliano Manfren, Ph.D. student, Politecnico di Milano

INDEX

INTRODUCTION

A methodological framework and a list of available software tools for distributed generation projects implementation and local energy planning is presented. Their main features, license type, website and scientific references are listed. The aim of this work is to present practical tools and a general framework to analyze energy, economic and environmental performances of DG systems in a community and evaluate possible scenarios dealing with DG adoption. The models and software tools presented are very different each other and are designed to support different phases in an efficient community project implementation.

1 MODELING TOOLS

In this section a list of tools for distributed energy resources and micro-grid projects analysis and implementation.

Geographic information systems and spatial planning tools

NAME	**ARCGIS**
AUTHORS/DEVELOPERS	ESRI
COST/LICENSE	Proprietary software
CAPABILITIES	It is an integrated collection of GIS software products for building and deploying a complete geographical information system to perform spatial analysis, manage large amounts of data and produce cartographically appealing maps to support decision making process
INPUT	Geographic maps and related data
OUTPUT	Spatial analysis and processing of data
CONTACTS/WEBSITE	http://www.esri.com/software/arcgis/
REFERENCES	Moller B., "Changing wind-power landscapes: regional assessment of visual impact on land use and population in Northern Jutland, Denmark ", Applied Energy, Volume 83, issue 5, 2006, Pages 477-494 Ayoub N., Wang K., Kagiyama T., Seki H., Naka Y., "A Planning Support System for Biomass-Based Power Generation", 16th European Symposium on Computer Aided Process Engineering and 9th International Symposium on Process Systems Engineering, 2006, Elsevier Agnolotti V., Giger C., "SIMGIS, GIS for thermal simulation in the built environment", ESRI website

NAME	**PLACE^{3}S Planning for Community Energy, Economic and Environmental Sustainability**
AUTHORS/DEVELOPERS	California energy commission
COST/LICENSE	-
CAPABILITIES	PLACE^{3}S is an innovative planning method that integrates public participation, community development and spatial analysis within a geographical information system framework. The aim of this model is to help public administrations creating local economic development, job opportunity, reducing at the same time environmental impact and fossil resources use; in particular a great importance in the model is given to mobility and suburban sprawl problem. It is fundamental to support, with the help of adequate tools, implementation process through a step by step results monitoring and, for this reason, a GIS tool is fundamental. Sustainable energy use and environmental impact mitigation are key factors in advanced community planning and poses several problems: reduction of traffic congestion, improvement in air quality and environmental quality in the built environment, reduction of costs for infrastructures, preservation of landscape and wildlife, promotion of local economic development and job opportunity
INPUT	Demography data, industrial, residential and tertiary energy consumption data, employment statistics, building's technical specifications, infrastructures lay-out, pollution data, meteorological data
OUTPUT	Scenarios of energy consumption evolution in a community, environmental conditions, infrastructures, industrial, residential and commercial sites location and lay-out.
POTENTIAL	Evaluate possible scenarios for energy efficient community implementation. The methodology and procedure can be taken as a benchmark for planning processes that assume energy efficiency and renewable energy as key factors
CONTATTO/SITO WEB	http://www.energy.ca.gov/places/
REFERENCES	Newhouse G., "PLACE3S, Planning for Energy Efficiency", Energy and Environment in the California-Baja, 1995, San Diego State University Press Frank L. D., Kavage S., "Urban Planning and Public Health: A Story of Separation and Reconnection" Journal of Public Health Management & Practice, Volume 14, issue 3, May/June 2008, Pages 214-220

Distributed generation simulation tools

NAME	HOMER
AUTHORS/DEVELOPERS	NREL, National Renewable Energy Laboratory, USA
COST/LICENSE	Freeware
CAPABILITIES	Computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed generation (DG) applications. HOMER's optimization and sensitivity analysis algorithms is used to evaluate the economic and technical feasibility of a large number of technology options and to account for variation in technology costs and energy resource availability. Power sources that can be modeled include: solar photovoltaics (PV), wind turbines, run-of-river hydro power, diesel, gasoline, biogas, alternative, co-fired and custom-fueled generators, electric utility grids, microturbines, and fuel cells. Storage options include: battery banks and hydrogen.
INPUT	Load curve (electrical,thermal) up to one minute resolution, technology efficiences and features, O&M costs, emission constraints and sensitivity parameters
OUTPUT	Optimization and sensitivity analysis of the system involving energy production, fuel consumption, emissions and costs with graphs and detailed data report (export format .xml/.html)
TYPE OF CALCULATION/ ALGORITHMS	Up to one minute time-step analysis, optimization-sensitivity parametric analysis. Two options to meet electrical energy demand: load following and cycle charging (storage options)
CONTACTS/WEBSITE	http://www.nrel.gov/homer
REFERENCES	Iqbal M.T. “A feasibility study of a zero energy home in Newfoundland” Renewable Energy, Volume 29, issue 2, 2004, Pages 277-28 Khan M.J., Iqbal M.T. “Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland” Renewable Energy, Volume 30, issue 6, 2005, Pages 835-854 Farret F.A., Simoes M.G. “Integration of alternative sources of energy”, 2006 John Wiley & Sons, Inc.

NAME	**RETScreen**
AUTHORS/DEVELOPERS	RETScreen International, CANADA
COST/LICENSE	Freeware
CAPABILITIES	RETScreen International Clean Energy Project Analysis Software can be used world-wide to evaluate the energy production, life-cycle costs and greenhouse gas emission reductions for various types of energy efficient and renewable energy technologies (RETs). The software also includes product, cost and weather databases, and a detailed online user manual. The RETScreen International Online Product Database provides users access to contact information for more than 1,000 clean energy technology manufacturers around the globe, including direct Website and Internet links from within the RETScreen software and from the Website (Marketplace). In addition, the database provides access to pertinent product performance and specifications data for a number of these manufacturers. These data can be "pasted" to the relevant cells within the RETScreen software. The RETScreen software currently includes modules for evaluating: wind energy, small hydro, solar photovoltaics (PVs), combined heat and power, biomass heating, solar air heating, solar water heating, passive solar heating, ground-source heat pumps, and refrigeration.
INPUT	Weather data, resources availability, technology efficiences and features, O&M costs, emission constraints and sensitivity parameters (several informations are provided in the software dabatase)
OUTPUT	Energy production, life cycle cost, emissions, load curve, risk analysis, data export in .xls format
TYPE OF CALCULATION/ ALGORITHM	Excel based spreadsheets, sensitivity parametric analysis, risk analysis
POTENTIAL	Evaluate the techno-economic feasibility of a local single clean energy technologies application
CONTACTS/WEBSITE	http://www.retscreen.net
REFERENCES	Thevenard, D. Leng, G. Martel, S. “The RETscreen model for assessing potential projects” Photovoltaic Specialists Conference, 2000. Conference Record of the Twenty-Eight IEEE Bakos, G.C. , Soursos “Techno-economic assessment of a stand-alone PV/hybrid installation for low-cost electrification of a tourist resort in Greece” Applied Energy, Volume 73, issue 2, 2002, Pages 183-193 Bakos, G.C., Soursos , Tsagas N.F. “Techno-economic assessment of a building-integrated PV system for electrical energy saving in residential sector” Energy and Buildings, Volume 35, issue 8, 2003, Pages 757-762 Houri A.. “Solar water heating in Lebanon, Current status and future prospects” Renewable Energy, Volume 31, issue 5, 2006, Pages 663-675

NAME	**HYDROGEMS, Hydrogen Energy Models**
AUTHORS/DEVELOPERS	Institute for Energy Technology IFE, Norway
COST/LICENSE	Included in TRNSYS 16 simulation environment
CAPABILITIES	Library of models for simulating integrated hydrogen systems based on renewable energy. The HYDROGEMS library includes models for power producing equipment, such as photovoltaic (PV) generators, wind energy conversion systems (WECS), diesel engine generator systems (DEGS), proton exchange membrane fuel cells (PEMFC), and alkaline fuel cells (AFC). Models for water electrolysis and H2-storage are also included, along with models for lead-acid battery, power conditioning equipment and logical controls. The models have been designed to be as general as possible, so that specific components characteristics obtained from manufacturers, or from experiments, readily can be added to a data base. In general, component specific parameters, such as those describing current-voltage characteristics (*IV*-curves) of PV, are calculated from manufacturer's data, while design parameters, such as number of cells in series and/or parallel, are set inside a simulation assembly. The HYDROGEMS components are written as FORTRAN subroutines and are primarily designed to run within the simulation environment TRNSYS and EES
INPUT	Detailed parameters and features of hybrid energy system components, weather data, load data
OUTPUT	Detailed data and graphs about energy production and operating parameters of the hybrid system
TYPE OF CALCULATION/ ALGORITHMS	Transient simulation
POTENTIAL	Dynamic simulation of H2RES hybrid systems
CONTACTS/WEBSITE	http://www.hydrogems.no/
REFERENCES	St. Germain L., Wild P., Rowe A., "Wave Power Integration with a Renewable Hydrogen Energy System", IGEC-1 Proceedings of the International Green Energy Conference 12-16 June 2005, Waterloo, Ontario, Canada, Paper No. 085 Corsini A., Gamberale M., Rispoli F., "Assessment of Renewable Energy Solutions in an Italian Small Island Energy System Using a Transient Simulation Model", Journal of Solar Energy Engineering, Volume 128, issue 2, 2006, Pages 237-244 Samaniego J., Alija F., Sanz S., Valmaseda C., Frechoso F., "Economic and technical analysis of a hybrid wind fuel cell energy system", Renewable Energy, Volume 33, issue 5, 2008, Pages 839-845

Energy planning and energy system optimization tools

NAME	LEAP, Long Range Energy Alternatives Planning
AUTHORS/DEVELOPERS	Stockholm Environment Institute (SEI)
COST/LICENSE	Free for Non OECD non-profit and research organizations, 500$ for a single licence for non-commercial use
CAPABILITIES	LEAP is a comprehensive integrated scenario-based energy-environment modelling tool. Its scenarios account for how energy is consumed, converted and produced in a given energy system under a range of alternative assumptions on population, economic development, technology, price and so on. LEAP is primarily an accounting system but users can also build econometric and simulation-based models. It supports both final and useful energy demand analyses as well as detailed stock-turnover modelling for transportation and other analyses. On the supply side it supports a range of simulation methods for modelling both capacity expansion and plant dispatch. LEAP includes a Technology and Environmental Database (TED) containing data on the costs, performance and emission factors for over 1000 energy technologies. It can be used to calculate the emissions profiles and to create scenarios of non-energy sector emissions and sinks (e.g. cement production, land-use change, solid waste, etc.).
INPUT	Load duration curve (electrical, thermal), energy sources availability data, technology efficiencies and features, O&M costs, GDP, interest rate, population growth rate, emission constraints. Example of input data are provided in the software technology database
OUTPUT	Detailed report and graphs about selected energy scenario
TYPE OF CALCULATION/ ALGORITHM	Physical accounting, sensitivity parametric analysis
POTENTIAL	Different energy scenario evaluation, integrated Energy/Environment Analysis
CONTACTS/WEBSITE	http://www.energycommunity.org
REFERENCES	Pandey, R. “Energy policy modelling: agenda for developing countries ” Energy Policy, Volume 30, issue 2, 2002, Pages 97-106 Shin H.C. “Implications of transportation policies on energy and environment in Kathmandu Valley, Nepal” Energy Policy, Volume 31, issue 14, 2003, Pages 1493-1507 Nakata T. “Energy-economic models and the environment” Progress in Energy and Combustion Science, Volume 30, issue 4, 2004, Pages 417-475 Shin H.C., Park J.W., Kim H.S., Shin E.S. “Environmental and economic assessment of landfill gas electricity generation in Korea using LEAP model” Energy Policy, Volume 33, issue 10, 2005, Pages 1261-1270

NAME	**EnergyPLAN**
AUTHORS/DEVELOPERS	Dep. of Development and Planning, Aalborg University, DENMARK
COST/LICENSE	Freeware
CAPABILITIES	The EnergyPLAN model is a computer model for Energy System Analysis. The model has been developed and expanded on a continuous basis since 1999 .The analysis is carried out in hour-by-hour steps and the consequences of each strategy With EnergyPLAN, it is possible to analyse the consequences of different energy investments and design suitable energy planning strategies in relation to technical regulation and economic optimisation. The model can be used for different kinds of energy system analysis: technical analysis, market exchange analysis, feasibility studies.
INPUT	Load curve (electrical, thermal) with one hour resolution, weather data and energy sources availability data, technology efficiencies and features, O&M costs, emission constraints and optimization strategy (different types of technical optimization and market optimization). Example of input data are provided in the software database in .txt format
OUTPUT	Report and graphs about energy production, costs, emissions, data export in .txt format
TYPE OF CALCULATION/ ALGORITHM	One hour time-step analysis, optimization-sensitivity parametric analysis. Four options to meet electrical/thermal energy demand with different types of technical optimization and market optimization
POTENTIAL	Evaluate the techno-economic feasibility of a large scale DG system project under constraints
CONTACTS/WEBSITE	http://energy.plan.aau.dk/
REFERENCES	Lund H., Duic N, Krajacic G., Carvalho M.G. “Two Sustainable Energy System Analysis Models. A comparison of methodologies and results”, 2005 Lund H., Munster E. “Integrated energy systems and local energy markets” Energy Policy, Volume 34, issue 10, 2006, Pages 1152-1160 Lund H., Munster E. “Integrated transportation and energy sector CO2 emission control strategies” Transport Policy, Volume 13, issue 5, 2006, Pages 426-433 Lund H. “Renewable energy strategies for sustainable development” Energy, Volume 32, issue 6, 2007, Pages 912-919 Mathiesen B.V., Lund H., Norgaard P. “Integrated transport and renewable energy system” Utilities Policy, Volume 16, 2008, Pages 107-116

NAME	**DER-CAM Distributed Energy Resource Customer Adoption Models**
AUTHORS/DEVELOPERS	Distributed Energy Resources, Berkeley Lab
COST/LICENSE	Freeware, but requires GAMS programming language license
CAPABILITIES	DER-CAM is an economic model of customer DER adoption implemented in the General Algebraic Modelling System (GAMS) optimization software, The objective of the model is to minimize the cost of operating on-site generation and combined heat and power (CHP) systems, either for individual customer sites or a micro-grid: – Which is the lowest-cost combination of distributed generation technologies that a specific customer can install? – What is the appropriate level of installed capacity of these technologies that minimizes cost? – How should the installed capacity be operated so as to minimize the total customer energy bill? It is assumed that the customer desires to install distributed generation to minimize the cost of energy consumed on site. Consequently, it should be possible to determine the technologies and capacity the customer is likely to install and to predict when the customer will be self-generating electricity and/ or transacting with the power grid, and likewise when purchasing fuel or using recovered heat.
INPUT	Load curve (electrical, thermal) with one hour resolution, technology efficiencies and features, electric energy tariffs, natural gas price, initial investment capital, operation and maintenance costs, investment rate of interest
OUTPUT	Optimal plant size, dispatch strategy and cost of produced energy (thermal and electrical)
TYPE OF CALCULATION/ ALGORITHM	Optimization analysis through linear programming
POTENTIAL	Evaluate techno-economic feasibility and dispatch optimization of distributed generation systems.
CONTACTS/WEBSITE	http://der.lbl.gov/dercam.html
REFERENCES	Zhou N., Gao W., Firestone R., Stadler M., Marnay C., Nishida M., “An Analysis of the DER Adoption Climate in Japan Using Optimization Results for Prototype Buildings with U.S. Comparisons”, June 2006 Siddiqui A., Marnay C., “Distributed Generation Investment by a Microgrid Under Uncertainty”, June 2006 Firestone R., Stadler M., Marnay C., “Integrated energy system dispatch optimization”, June 2006

NAME	DEECO
AUTHORS/DEVELOPERS	Institut für Energietechnik, Technische Universität Berlin, Germany
COST/LICENSE	Open source (but requires UNIX proprietary C++ libraries)
CAPABILITIES	Deeco is an energy systems modelling environment which is used to define, guide, and evaluate sustainability improvements of all types, typical goals include less CO2 and reduced fossil fuel dependence. It can be used to test a number of potential improvements and will naturally include any synergetic or counteractive interactions which arise, hence the term "integration modelling". Improvements can be classified as hard, for instance, enhanced plant performance or revised connectivity, or soft, such as targeted demand modification or amended operational policy. Deeco represents a given system as a network of dynamic plant whose state may evolve. Deeco determines best-practice operation as defined by the selected management objective, using recursive dynamic optimization techniques. Analysis proceeds by comparison with some pre-determined reference case. Deeco is normally used to compute sustainability gains versus financial cost relative to some assessment of business-as-usual.
INPUT	Load curve (electrical, thermal), one hour resolution, weather data and energy sources availability data, technology efficiencies and features, O&M costs, emission constraints and optimization strategy (different types of technical optimization and market optimization)
OUTPUT	Detailed report and graphs about energy/exergy, costs, emissions, data export in .xml format
TYPE OF CALCULATION/ ALGORITHM	One hour time-step analysis, optimization-sensitivity parametric analysis. Various options to meet electrical/thermal energy demand with different types of technical optimization and market optimization
POTENTIAL	Evaluate the techno-economic feasibility of a large scale DG system project under constraints, investigating possible options and optimization
ENERGY/EXERGY	Energy analysis/Exergy analysis
CONTACTS/WEBSITE	http://www.iet.tu-berlin.de/deeco/
REFERENCES	Bruckner T., Morrison R., Handley C., Patterson M., “High-Resolution Modelling of Energy-Services Supply Systems Using DEECO: Overview and Application to Policy Development” Annals of Operations Research, Volume 121, issue 1-4, 2003, Pages 151-180 Bruckner T., Groscurth H.M., Kummel R., “Competition and synergy between energy technologies in municipal energy systems” Energy, Volume 22, issue 10, 1997, Pages 1005-1014

2 SELECTED TOOLS FOR COMMUNITY CASE STUDIES

For energy consumption pattern analysis and urban smart growth project implementation a GIS software tool like ArcGIS by ESRI is essential first to store energy consumption data, building features, technical specifications of installed plants and land-use constraints on a spatial base. Algorithms for spatial processing of data, on the other side, enable us to rapidly identify energy consumption intensity and complementary energy needs in urban neighbourhood. This tool is useful also for representing data analysis on a spatial base and promoting public participation, for example, through Web-GIS applications that can be used via web without requiring software installation in the pc.
A part from this, two main approach seem to be suitable for our aims:

- to use HOMER to identify an approximately optimal system among different hypothesis, and have a first approximation of the optimal size of each component; in this case, at the end, further routine should be included for moving from an energy to an exergy analysis
- to use TRNSYS simulation environment, implementing time by time the energy demand of the community, the energy system for satisfying it and the equations for calculating exergy results.