STREAM Long-term Planning in Energy, Environment and Climate

Session Machine Learning for Energy Applications
Chair: Gilles GUERASSIMOFF (MINES ParisTech, CMA)

- **Machine-learning for energy, environment and climate**
  Valérie Roy (CMA MinesParisTech)
- **Machine learning for energy demand model from a load curve**
  Hamza MRAIHI (Centre for Applied Mathematics, MINES ParisTech)
  Edi Assoumou (Centre de Mathematiques Appliquees, Mines ParisTech)
  Gilles Guerassimoff (Centre for Applied Mathematics, Mines ParisTech)
  Valérie Roy (CMA MinesParisTech)
- **Household behavior by load curve analysis with machine learning techniques**
  Ahmed CHAABANE (Centre for Applied Mathematics, MINES ParisTech)
  Gilles Guerassimoff (Centre for Applied Mathematics, Mines ParisTech)
  Valérie Roy (CMA MinesParisTech)

Session Modeling tools for Energy and Sustainable policy (1)
Chair: Sandrine SELOSSE (MINES ParisTech, CMA)

- **In decarbonizing the European electric sector - The role of interconnections**
  Seyram SIGGINI (Centre for Applied Mathematics, MINES ParisTech)
  Jerôme Gutierrez (Center for Applied Mathematics, Mines ParisTech-ARMINES)
  Sophie Demassey (CMA, Mines ParisTech)
  Edi Assoumou (Centre de Mathematiques Appliquees, Mines ParisTech)
- **Benefits of Energy Storage and Transmission Switching in Power Systems with High Renewable Energy Penetration**
  Meltem Peker (Industrial Engineering, Bilkent University)
  Ayse Selin Kocaman (Industrial Engineering, Bilkent University)
  Bahar Yetis Kara (Industrial Engineering, Bilkent University)
- **The influence of carbon storage and biomass potentials in the future development of Bioenergy with carbon capture and storage**
  Sandrine Selosse (MINES ParisTech, CMA)
- **An Optimization Model for Carbon Capture & Storage/Utilization vs. Carbon Trading and Its Application**
  Semra Agrali (Department of Industrial Engineering, MEF University)
  F. Gorkem Uctug (Izmir University of Economics)
  Burcin Atilgan Turkmen (Bilecik Seyh Edebali University)

Session Modeling tools for Energy and Sustainable policy (2)
Chair: Sandrine SELOSSE (MINES ParisTech, CMA)

- **EU and Norwegian Policy Analysis using CGE Modelling**
  Gerardo Perez Valdes (Teknologi og Samfunn, SINTEF)
- **The Canadian contribution to limiting global warming below 2 degree C: An analysis with NATEM**
  Olivier Bahn (GERAD and Decision Sciences, HEC Montréal)
  Kathleen Vaillancourt (ESMIA Consultants)
  Oskar Sigvaldason (SCMS Global)
- **A simplistic method for representing renewable gasses and fuels in an energy systems optimisation model**
  Ida Græsted Jensen (Management Engineering, Technical University of Denmark)
  Frauke Wiese (Technical University of Denmark)
  Rasmus Bramstoft (Technical University of Denmark)

STREAM Optimization in Renewable Energy Systems

Session Optimization of Energy Systems
Chair Welington de Oliveira (MINES ParisTech, CMA)

- **Energy Plant Operation and Installation Plan via Stochastic Programming**
  Tomoki Fukuba (Department of Industrial and Management Systems Engineering, Waseda University)
  Shuichi Isomura (Department of Industrial and Management Systems Engineering, Waseda University)
  Takayuki Shiina (Department of Industrial and Management Systems Engineering, Waseda University)
- **Stochastic dual dynamic programming with modified cuts applied to the Brazilian long-term** hydrothermal scheduling problem.
  Welington de Oliveira (MINES Paristech)
  Felipe Beltrán (Federal University at Santa Catarina)
  Guilherme Fredo (UFSC/LabPlan)
  Erlon Finardi (Universidade Federal de Santa Catarina)
- **On the Determination of Turkish Natural Gas Balancing and Wholesale Market Prices**
  Kürşad Derinkuyu (Industrial Engineering, TOBB University of Economics and Technology)
  Rabia Taspinar (Industrial Engineering, TOBB University of Economics and Technology)
  Furkan EZER (Industrial Engineering, TOBB University of Economics and Technology)
  Melike Yıldız (Industrial engineering, Tobb etü)
  Seher Onay (Industrial Engineering, TOBB University of Economics and Technology)
  Sevde Nur Ozbolat (Industrial engineering, Tobb etü)
  Pelin Tekin (Industrial Engineering, TOBB University of Economics and Technology)

Détail des sessions avec les abstracts ci-dessous

EURO2018
29th European Conference on Operational Research
VALENCIA, JULY 8-11, 2018

EURO
THE ASSOCIATION OF EUROPEAN OPERATIONAL RESEARCH SOCIETIES

SEIO
Sociedad de Estadística e Investigación Operativa

STREAM Long-term Planning in Energy, Environment and Climate

Session Machine Learning for Energy Applications
Chair: Gilles GUERASSIMOFF (MINES ParisTech, CMA)

- **Machine-learning for energy, environment and climate**
  Valérie Roy (CMA MinesParisTech)

The actual conjunction of multi-core high-powerful computers, very large storage capacities, large transmission speed of computer networks, decisive breakthrough in algorithmic and in algorithm distribution allowed for the development, dissemination and democratization of techniques related to big data in many areas, in particular in the energy sector. If the data has of course always been used in the field of production and transformation of energy, the operated models were classically physic-based behavioral models. This approach is now supplemented and even rivaled by decision-support models based on machine-learning techniques taking advantages of the huge amounts of data currently available, that these data are directly generated by the energetic systems or help describing their environments. This talk will introduce machine learning techniques and illustrate them on applications from the energy domain. The approach, intentionally didactic, will nevertheless introduce the general scientific concepts underlying the techniques and their hypotheses of use and give an idea of the complexity of their implementations. The validation of those models will then be discussed.

- **Machine learning for energy demand model from a load curve**
  Hamza MRAIHI (Centre for Applied Mathematics, MINES ParisTech)
  Edi Assoumou (Centre de Mathematiques Appliquees, Mines ParisTech)
  Gilles Guerassimoff (Centre for Applied Mathematics, Mines ParisTech)
  Valérie Roy (CMA MinesParisTech)

The strong deployment of intermittent renewable energy in the European electric system has to be anticipated to optimize the power plant planning. A better knowledge of the correlation between the hour step load curves and the national level in the European country is crucial. Depending on the size of the future horizon we are regarding, the demand level determines the profitability of the solutions for the flexibility. The results presented in this communication represent the first step in the assessment of the forecasted electric load curve for a residential park of buildings. After a statistical analysis of the time series proposed by the European Network of Transmission System Operators for Electricity, we show some results of the application of machine learning technique for the demand projection characterization for prospective studies.

- **Household behavior by load curve analysis with machine learning techniques**
  Ahmed CHAABANE (Centre for Applied Mathematics, MINES ParisTech)
  Gilles Guerassimoff (Centre for Applied Mathematics, Mines ParisTech)
  Valérie Roy (CMA MinesParisTech)

With the recent deployment of the smart meters in a French context, energy efficiency improvement in residential sector can be approach by the households load curve analysis completed by a detailed survey of the household's characteristics

and habits. As buildings are becoming more and more efficient, the energy consumption tends to be more and more behaviorally influenced. It is important to be able to quantify this part to give the pertinent advices to the users to improve their relationship to energy consumption. We present the first result obtained by machine learning technique application on the coupled information given by their load curve and their status and habits. This exploration gives some patterns that can be coupled with some population categories that may help an energy provider having a new customer similar to a category to advise him in improving its energy consumption performance.

Session Modeling tools for Energy and Sustainable policy (1)

Chair: Sandrine SELOSSE (MINES ParisTech, CMA)

- **In decarbonizing the European electric sector - The role of interconnections**
  Seyram SIGGINI (Centre for Applied Mathematics, MINES ParisTech)
  Jerôme Gutierrez (Center for Applied Mathematics, Mines ParisTech-ARMINES)
  Sophie Demassey (CMA, Mines ParisTech)
  Edi Assoumou (Centre de Mathematiques Appliquees, Mines ParisTech)

During the recent years, renewable energy clearly appeared as an effective way to decarbonize the European production mix and then increasing levels of penetration of renewables are expected. High share of renewable then raise many questions over the behavior of electric systems. The intermittent production of solar and wind capacities affects the flexibility of the system i.e. its ability to respond to changes in power demand and generation. This also brings more concern on the system's adequacy. Differentiate programs at countries level towards CO2 reduction in the electric system noticeably increase the disparity between the production mixes and therefore bring up concern to the electricity flows within the European system. In this context, interconnections facilitate integration and permits to build a spatial aggregation. They constitute the perfect outlet for the surplus of energy generated within a country (inversely the perfect way to satisfy a lacking generation) but a question is still pending on their usage and the required capacities in the future with regard to the upcoming renewable penetration. The aim of our work is to provide, through prospective modelling up to 2050, comparisions between possible production mixes in Europe, their implication on energy exchanges between countries and therefore give elements for reflexions on the cost effective way to achieve energy transition at the European level.

- **Benefits of Energy Storage and Transmission Switching in Power Systems with High Renewable Energy Penetration**
  Meltem Peker (Industrial Engineering, Bilkent University)
  Ayse Selin Kocaman (Industrial Engineering, Bilkent University)
  Bahar Yetis Kara (Industrial Engineering, Bilkent University)

Increasing the share of renewable energy sources in electricity generation helps address the concerns about global warming and dependence on fossil fuels. However, high penetration of renewable energy sources into the power systems may affect the power system reliability and stability. To use these clean sources without endangering the power system, various control mechanisms such as energy storage systems, demand side management, renewable energy curtailment and transmission switching are utilized. In this study, we analyze the effect of transmission switching on the total investment and operational costs, sizing and sitting decisions of energy storage systems, and changes in the load-shedding and renewable energy curtailment amounts. An extensive computational study on the IEEE 24-bus power system with wind and solar as available sources demonstrates that total cost and total storage capacity can be decreased up to 17% and 50%, respectively, when transmission switching is used in the system.

- **The influence of carbon storage and biomass potentials in the future development of Bioenergy with carbone capture and storage**
  Sandrine Selosse (MINES ParisTech, CMA)

The challenges of climate change involve rethinking the world's energy system. In particular, carbon capture and storage technologies are still presented as a solution to reach ambitious decarbonization targets, and particularly when associated with bioenergy resources. However, avoiding the required Gt of CO2 emissions by investing in CCS technologies supposes the development of carbon storage capacities and, when associated with bioenergy, an adequate and sustainable potential of biomass resources. This analysis, conducted with the optimization model TIAM-FR (TIMES Integrated Assessment Model, a bottom-up, long-term and multiregional model), highlights the role of these elements in the future development of the BECCS option. More precisely, based, on the one hand, on a specific methodology of biomass potential assessment, and, on the other hand, detailed data on storage potential, including onshore and offshore classification, this study aims to discuss whether such potentials may be a limit to the development of (bioenergy with) carbon capture and storage technologies. And at what extend. We thus investigate various scenarios with different levels of potentials and different climate targets on the long-term.

- **An Optimization Model for Carbon Capture & Storage/Utilization vs. Carbon Trading and Its Application**
  Semra Agrali (Department of Industrial Engineering, MEF University)
  F. Gorkem Uctug (Izmir University of Economics)
  Burcin Atilgan Turkmen (Bilecik Seyh Edebali University)

We consider fossil-fired power plants that operate in an environment where a cap and trade system is in operation. These plants need to choose between carbon capture and storage (CCS), carbon capture and utilization (CCU), or carbon trading in order to obey emissions limits enforced by the government. We develop a mixed-integer programming model that decides on the capacities of carbon capture units, the transportation network that needs to be built for transporting the carbon captured, and the locations of storage sites, if they are decided to be built. Main restrictions on the system are the minimum and maximum capacities of the different parts of the pipeline network, the amount of carbon that can be sold to companies for utilization, and the capacities on the storage sites. Under these restrictions, the model aims to minimize the net present value of the sum of the costs associated with installation and operation of the carbon capture unit and the transportation of carbon, the storage cost in case of CCS, the cost (or revenue) that results from the emissions trading system, and finally the negative revenue of selling the carbon to other entities for utilization. We implement the model by using data associated with two coal-fired power plants located in different regions of Turkey. We choose enhanced oil recovery (EOR) as the process for carbon utilization. The results show that CCU is preferable to CCS if there is sufficient demand in the EOR market.

Session Modeling tools for Energy and Sustainable policy (2)
Chair: Sandrine SELOSSE (MINES ParisTech, CMA)

- **EU and Norwegian Policy Analysis using CGE Modelling**
  Gerardo Perez Valdes (Teknologi og Samfunn, SINTEF)

Energy Policies in general are complex instruments with wide-ranging mechanisms and effects on the economic systems they impact. Using the flexible CGE model REMES, we have, over the last five years, analysed different aspects of the Norwegian and the European Energy System. Case studies performed with REMES address international oil prices, efficiency in the transport system, introduction of hydrogen, and deployment of energy-efficient building technologies. We present here short details of the implementation of these policy mechanisms.

- **The Canadian contribution to limiting global warming below 2 degree C: An analysis with NATEM**
  Olivier Bahn (GERAD and Decision Sciences, HEC Montréal)
  Kathleen Vaillancourt (ESMIA Consultants)
  Oskar Sigvaldason (SCMS Global)

Canada committed to reduce its greenhouse gas (GHG) emissions by 30% below 2005 levels, by 2030, and by 70% to 90% below 2005 levels, by 2050. These challenging commitments require special consideration of the energy sector in

Canada. The main objective of this presentation is to identify different decarbonization pathways that would allow Canada to participate in global mitigation efforts to prevent climate changes. We analyse four GHG mitigation scenarios with increasing levels of mitigation efforts for 2050 using the NATEM regional optimization model. NATEM belongs to the TIMES family of models developed within the Energy Technology Systems Analysis Program of the International Energy Agency. It relies on the concept of a Reference Energy System that describes energy value chains from primary energy to useful energy. NATEM is cast as a dynamic linear programming model, where the objective is to minimize the net present worth cost of the energy system. The main transformations in the energy system include significant energy conservation and efficiency improvements, greater penetration of electricity in all end-use sectors (up to 64% of total consumption in 2050), as well as an important increased use of bioenergy in 2050. On the supply side, this translates into a rapid decarbonization of electricity production and a shift away from fossil fuel production and imports.

- **A simplistic method for representing renewable gasses and fuels in an energy systems optimisation model**
  Ida Græsted Jensen (Management Engineering, Technical University of Denmark)
  Frauke Wiese (Technical University of Denmark)
  Rasmus Bramstoft (Technical University of Denmark)

With an increase in variable renewable energy production in the heat and power system, integration with the gas system is a way to get more flexibility in the overall energy system. Renewable gasses and fuels as, e.g., biogas, can be upgraded by adding hydrogen and thereby serve as a substitute for natural gas and conventional transportation fuels. As continued research within hydrogen conversion and storage technologies shows promising cost reductions and efficiency increases, it seems inevitable to implement these technologies in energy systems models. We present a simplified method to include renewable gasses and fuels and their upgrading, as well as hydrogen production and consumption in the energy systems model, Balmorel. We compare the results from using the simplified method with the results obtained using a more detailed formulation of gas and fuel production in the spatio-temporal network optimisation model, OptiFlow, where the production and upgrading processes are included in the modelling. By comparing the methods, we evaluate the importance of the loss of information in the simplified method compared to the detailed formulation, with respect to correspondence between the two solutions in, e.g., overall cost, investments, and running time.

STREAM Optimization in Renewable Energy Systems

Session Optimization of Energy Systems
Chair Welington de Oliveira (MINES ParisTech, CMA)

- **Energy Plant Operation and Installation Plan via Stochastic Programming**
  Tomoki Fukuba (Department of Industrial and Management Systems Engineering, Waseda University)
  Shuichi Isomura (Department of Industrial and Management Systems Engineering, Waseda University)
  Takayuki Shiina (Department of Industrial and Management Systems Engineering, Waseda University)

The spread of renewable energy is an important problem on a global scale. In large facilities such as factories and shopping centers, introduction of renewable energy is desired. However, when renewable energy is introduced, the energy plant operation plan needs to consider the uncertainty of its output. We develop a stochastic programming model of energy plant at large facilities when solar power generation and storage battery are introduced. The uncertainty of the output of solar power generation is represented by a set of discrete scenarios, and the expected value of the operation cost is minimized. The stochastic programming model is formulated using nonlinear constraints because it is necessary for a real operation plan. This model can be transformed into a mixed integer programming problem. For the nonlinear constraints, we use piecewise linear approximation and reformulate the model using SOS2 constraint. As a result, it became possible to obtain exact solutions. In this model, the decision variable increases according to the number of scenarios and points of piecewise linear approximation, and it becomes a very large mixed integer programming problem. We show the usefulness of the stochastic programming model by comparing it with the deterministic model. As

an economic assessment, we show the recovery period for the initial investment of solar power generation and storage battery.

- **Stochastic dual dynamic programming with modified cuts applied to the Brazilian long-term hydrothermal scheduling problem.**
  Welington de Oliveira (MINES Paristech)
  Felipe Beltrán (Federal University at Santa Catarina)
  Guilherme Fredo (UFSC/LabPlan)
  Erlon Finardi (Universidade Federal de Santa Catarina)

In systems with hydraulic predominance, the long-term hydrothermal scheduling problem (LTHS) is usually formulated as a multistage stochastic program whose objective is to obtain an implementable power generation policy providing minimal costs (on average, or based on some risk measure). A classical optimization technique for solving LTHS problems is the stochastic dual dynamic programming (SDDP), which employs two main steps: a forward step for generating trial policies, and a backward one to construct Benders-like cuts. As the SDDP is a sort of cutting-plane method, it can exhibit slow convergence when dealing with large-scale optimization problems. In order to accelerate the SDDP method, we modify its cuts in the forward step by employing some ideas related to the Chebyshev center of the SDDP subproblems' feasible sets. Essentially, the cuts are lifted by a parameter that vanishes along the iterative process without compromising convergence analysis. Numerical assessments on the large-scale Brazilian LTHS problem with individualized decisions per plant, over a five-year planning horizon with monthly decisions, indicate that the new proposal significantly accelerates the SDDP method performance.

- **On the Determination of Turkish Natural Gas Balancing and Wholesale Market Prices**
  Kürşad Derinkuyu (Industrial Engineering, TOBB University of Economics and Technology)
  Rabia Taspinar (Industrial Engineering, TOBB University of Economics and Technology)
  Furkan EZER (Industrial Engineering, TOBB University of Economics and Technology)
  Melike Yıldız (Industrial engineering, Tobb etü)
  Seher Onay (Industrial Engineering, TOBB University of Economics and Technology)
  Sevde Nur Ozbolat (Industrial engineering, Tobb etü)
  Pelin Tekin (Industrial Engineering, TOBB University of Economics and Technology)

European exchanges and system operators are responsible for balancing of natural gas consumption activities. Starting from 2018, Turkey has been establishing natural gas balancing and spot markets. System operator (BOTAS) and Turkish exchange (EXIST) developed a Continuous Trading Platform (CTP) to balance natural gas imbalances as well as to manage trading activities in the wholesale market. This study first gives a brief summary of the natural gas market structures. Then, we provide the alternative formulation and solution approaches to the natural gas balancing and wholesale markets, where difficulties appear in practice. Three auction mechanisms are introduced and modeled by using mixed integer non-linear programming (MINLP). Also, a simulation model is designed to understand behavior of market participants. Lastly, we discuss the future trends in the natural gas wholesale markets.

Session Optimization in Renewable Energy Systems 3

Chairs: Nadia Maïzi (MINES ParisTech) and Sadia Samar Ali (Department of Industrial Engineering, King Abdul-Aziz University, College of Engineering for Girls)

Session Optimization in Renewable Energy Systems 4

Chairs: Nadia Maïzi (MINES ParisTech) and Serap Ulusam Seckiner (Industrial Engineering, University of Gaziantep)

Session Optimization in Renewable and Energy Systems 2

Chairs: Nadia Maïzi (MINES ParisTech) and Ayşe Mutlu Derya (Mathematics, TED University)