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Waste-heat recovery potential for district heating systems under diverse pricing schemes:

a bi-level modelling approach

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Optimal Operation of Energy Systems

Cluster: OR in Energy
Invited session
Chair: *Rodrigo A. Carrasco*

1 - Optimal Operation of a Green Hydrogen Plant using Wind Energy and BESS
Andrés Lagos

The objective of this study is to optimize the operation of the Green Hydrogen Plant 'Haru Oni' in Magallanes, Chile. At first, a perfect information model was created and a simulator was programmed that would help to evaluate the different proposed policies using wind data on site. Then the problem was solved using a Markov Decision Process (MDP) that performed 5.18% less than the global optimum, that is the perfect information model. Other policies were studied in comparison with the MDP solution using the simulator.

2 - Tightening bigMs for Optimal Transmission Switching
Salvador Pineda Morente, *Juan Miguel Morales*, *Álvaro Porras Cabrera*, *Concepción Domínguez*

The optimal transmission switching (OTS) problem determines the lines to switch off in an electricity network to reduce the operation cost. Using the linearized version of the power flow equations, the OTS problem can be formulated as a mixed-integer linear programming model, including large enough constants. When these constants are too high, however, the branch-and-bound algorithms used to solve the problem become computationally intensive due to poor relaxations. In this work, we present an efficient methodology to find tight values for these large enough constants. By doing so, we can find the global optimum of the OTS problem in significantly less time.

3 - Prescriptive scenario generation for solar energy management with storage
Rodrigo A. Carrasco

Governments have pushed for a higher penetration of variable and intermittent energy sources to alleviate the effects of climate change. Furthermore, storage systems have seen their prices drop significantly and are considered the key to dealing with the variability of some renewable energy sources.

This talk presents a novel approach to scheduling storage units in a photovoltaic generation system based on stochastic optimization. A common approach to take advantage of historical data for stochastic optimization has been to use machine learning techniques to compute relevant scenarios. Instead of this "predict THEN optimize" strategy, we show that using a combined "predict AND optimize" approach results in better recommendations. The resulting scenarios capture the relevant effects on the decision process - not just data features. We show experimental results applied to a real-life control system with limited computation capacity and further validate our results by testing the resulting schedules in an actual prototype.

Non-electricity Energy Models

Cluster: OR in Energy
Invited session
Chair: *Rodrigo Moreno*

1 - An Investigation of the Interaction Evidence between Carbon Credits and Crude Oil Prices of the International Markets
Renato Barros Lima, *Andre Assis de Salles*

An essential production factor for economic activity, energy has a prominent place in the global economy. Since the end of the last century, concern about global warming has been the object of global policies and has encouraged the production of energy from renewable sources and the growth of the carbon credits market. Studies have been carried out on related topics, particularly on the oil and gas markets and their interaction with renewable energy and carbon credits markets, mainly concerning the interaction of prices practised in these markets. This work aims to verify the relationship between crude oil and carbon credits in international markets, specifically studying the interaction between the price returns practised in the markets for Brent crude oil and carbon credits traded in the first contract month of the futures market for these credits. The primary data comprised the weekly closing prices spanning from February 2009 to August 2022. Thus, this work refers to the transmission of shocks from crude oil prices to carbon credits prices. To achieve the objectives of this work, initially, a study of the basic assumptions of the time series used in the models estimated for this study was carried out. Next, the cointegration hypothesis tests between the time series of changes in oil prices and carbon credits traded in international markets were carried out concomitantly with implementing a bivariate vector model with error correction – VECM. This model estimation enabled inferences of the causality relationship between the oil price and carbon credit returns. Therefore, it analysed how the variation in prices practised in the crude oil market is absorbed in the variations in prices practised in the carbon credit market and conversely. The impulse-response functions obtained for these variables showed what magnitude shocks in one of the variables are absorbed by the other variable and their persistence in time. In addition, heteroscedastic econometric models constructed to observe the occurrence of volatility peaks and clusters were estimated, verifying how short-term shocks in the prices of these variables interact with risk in these markets and how these shocks persist over time. Finally, the behaviour of the dynamic correlation of these returns time series was studied based on the estimation of a multivariate GARCH model. Thus, inferences were made regarding the dynamics of volatility contagion between the two markets studied.

2 - Waste-heat recovery potential for district heating systems under diverse pricing schemes: a bi-level modelling approach
Juan Jerez, *Claire Bergaentzlé*, *Dogan Keles*

Data centres produce significant amounts of waste-heat, a valuable resource in cold climates where data centres tend to develop. District heating systems provide heat to multiple users, through a network of underground pipes, and may leverage waste-heat to substitute for other heating fuels, lowering heat supply cost and emissions, while providing additional revenue and reduced cooling needs for data centre operators. Waste-heat recovery projects involve expenses related to lifting the heat's temperature to the district heating network's standards and its transport; their economic viability depends on the long-term certainty of the waste-heat price paid by the utility and how frequently the utility requires it. Various factors influence these aspects, however, such as the utility's own production cost, level of heat demand, and applicable district heating regulations, giving the utility an informational edge. This work examines how different pricing schemes influence the effective utilization of waste-heat potential, based on the dispatch decisions of the utility's heating and data centre's cooling portfolios. We propose a bi-level optimisation problem to adequately model their interaction, testing pricing schemes based on fixed values, time-of-use, and carbon intensity. The upper-level problem captures the district heating utility's objective of minimizing heat supply costs, based on its generation portfolio and waste-heat pricing. The lower-level problem represents the data centre operator's objective of minimizing its cooling costs, while considering alternative cooling equipment, such as free-cooling and electric chillers, including revenues from heat sales. We also develop a single-level model for comparison purposes, where the utility directly controls the data centre's cooling portfolio. The results illustrate the allocation of economic benefits between the parties and the impacts on their operations. Specifically, we evaluate the heating plans displaced and changes to carbon emissions; from the data centre's perspective, we analyze the economic indicators of the waste-heat project and how it increases its electricity use. This study and its methodology provide valuable insights for stakeholders in identifying the specific benefits associated with waste-heat recovery projects and for policymakers in designing effective pricing schemes to maximize these benefits.

3 - A binary expansion approach for the water pump scheduling problem in large, high altitude water distribution networks
Denise Cariaga

The water pump scheduling problem is an optimisation model determining the water pumps to be turned on or off at each period. In this work, we tackle the optimal operation of a desalinated water system, with reservoirs and pumps sending water to mining companies at high altitudes. The optimisation of this process faces several difficulties derived from the following: i) the non-linearities of the friction loss equations along pipes and pumps and ii) many possible combinations of head pressure and flow leading to high computational costs, making it an NP-Hard problem. These limitations prevent solving the problem in a reasonable computational time in water distribution networks with more than two pumps and tanks, as occurs in different networks worldwide. Therefore, in this work, we develop new optimization models of the pump scheduling problem, using a binary expansion approach to tackle the non-linearities to minimize the systemic costs and the computational cost of the original MINLP. We tested these models in different network topologies and solved them with Julia and Gurobi.

Challenges in Energy Systems Planning

Cluster: OR in Energy
Invited session
Chair: *Angela Flores*

1 - Hybrid decomposition for power system planning under uncertainty
Angela Flores

An accurate representation of short-term flexibility issues in long-term planning models is required to accurately assess the value of investing in flexibility options. Uncertainty must also be captured in long-term planning models to anticipate future scenarios and avoid the risk of locking into inefficient investment decisions. Including both short-term flexibility requirements and long-term uncertainty in a unique planning framework, however, leads to large-scale multi-stage stochastic mixed-integer programming problems. Therefore, efficient solution methodologies are required. This work investigates possible ways of combining column generation, lagrangian relaxation, and Benders decomposition in a hybrid decomposition kmethod for efficiently solving power system planning problems under uncertainty, to improve convergence by exploiting the strengths of the different decomposition methods. The proposed hybrid decomposition is implemented using distributed computing. In this way, each decomposition approach is started in parallel, with the possibility of exchanging bounds and solutions between the methods. The solutions obtained at each iteration of the Benders decomposition and bundle method may be used to generate new columns for the column generation approach. Likewise, the columns obtained by column generation can be used to derive new cuts for Benders decomposition and the bundle method.

2 - A long-term generation and transmission expansion planning model considering desalination flexibility and coordination: A Chilean case study
Manuel Portilla Paveri, *Denise Cariaga*, *Alvaro Lorca*, *Miguel F. Anjos*

The electrical grids have undergone a great transformation, bringing new challenges to energy systems, such as new requirements to ensure the reliability of the network and the adequacy of supply and its balance with the energy demand. The need for new schemes allowing generation and/or demand to be adapted to energy variability become essential, and demand response is usually presented as one of these flexibility sources. In parallel, water scarcity worldwide and in Chile has increased in recent years, presenting itself as one of the great challenges arising soon. As an approach, Reverse Osmosis is presented as a mature technology, capable of supplying water on larger scales to various sectors from a practically inexhaustible source, the sea; it is a highly energy-demanding process, however, due to the use of high-pressure pumps used to desalinate the water through the membranes of the internal modules, where this consumption could mean more than 35% of the operating costs. In this context, this study develops a long-term planning model of the Chilean electricity system under various scenarios, considering the presence and implementation of desalination plants to respond to water scarcity from a centralized and coordinated point of view, taking advantage of the opportunities provided by flexible operation strategies of desalination plants, given by the nature of high-pressure pumps. These strategies enable a demand response source to minimize the impacts of the high-variable renewable energy sources power capacity expected in Chile. The study explores the value added to the system given by the coordination of desalination plants through defined signals, such as energy price, centralized dispatch in a water distribution system and demand response schemes. With this water-energy nexus model, the main objective is to identify the impact of high desalination participation scenarios on the power system dynamics and in transmission and generation capacity expansion planning. These main results aim to shed light on the need for investment, impact and alignment in decarbonization policies, new policies regarding desalination and links with the electrical system.

3 - Modern Preference Learning Model Evaluation for Individual Discrete Energy Policy Choices
Sheng Lun Cao, *Destenie Nock*

Decision aids for energy policy option recommendations can be customized for stakeholders by estimating individual stakeholder preferences using statistics and machine learning (ML). Learning individual preferences (behavioral choice rules) is difficult, however, due to the malleability of those choice rules, heterogeneity across decision-makers, and the limited availability of choice sets. It is currently unknown what estimation method can best estimate individual preferences, without prior knowledge of the choice rules decision-makers will use. This study evaluates four preference learning models (Multinomial Logistic Regression, Generalized Additive Model, Twinned Neural Network, and Gaussian Process), with respect to their capacity to learn and predict five choice rules exhibited by energy policy stakeholders (Linear Strong Utility, Monotonic Strong Utility, Ideal Point, Lexicographic Semiorder, and Multiattribute Linear Ballistic Accumulator). Three Monte Carlo experiments were performed to assess model performance when increasing a) number of attributes in the choice alternatives, b) number of training choice sets, and c) choice rule determinism. Preference learning models were further evaluated on a real energy policy discrete choice dataset. Some models can outperform others for individual choice rules; for example, GAM outperforms other models using limited choice sets in recovering Linear Strong Utility by 0.004 (TNN), 0.016 (MNL), and 0.027 (GP), as measured by Brier Score. No model dominates, however, in performance across all choice rules and contexts. Model performance improved by 8% to 68% in Brier Score with an increase in training choice sets and improved by 1% to 63% with an increase in choice rule determinism, but the impact of number of attributes differs by choice rule and model. All four models can learn and predict real energy policy discrete choices, with TNN outperforming other models by 0.006 (MNL), 0.025 (GP), and 0.199 (GAM) in Brier Score. This research explored the performance of modern preference learning models at the theoretical boundary and demonstrated a customizable individual energy policy decision aid is possible using preference learning.

Demand-Side Energy Optimization and Smart Grids

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Chair: *Young Lee*