Microgrid energy management with renewables and storage

PGMO Days 2016

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November, 2016

Presented by Bernardo Pagnoncelli

Outline

1. Introduction
2. The model
3. Results
4. Conclusions and future work

Background

- New technologies allow us to use weather-dependent energy generation
- Until 2035 it is estimated that 31% of generation will be from renewables (50% hydro)
- In addition, we are aiming at efficiency and cost-effectiveness of fossil-fueled generation (CHP plants, heat and power)
- The current efficiency level is around 33%, can reach 40%.

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- The importance of energy storage systems such as batteries and water tanks

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- The microgrid operation combines unit commitment with economic dispatch (hard problems!)
- Centralization versus Decentralization (the objectives are not obvious).
    - **Island mode** ⇒ minimize its own generation cost.
    - **Grid connected mode** ⇒ Can have contradicting goals with the main grid.

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- We assume there is a central grid (the network), external to the microgrid, from which energy can be bought and sold
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Elements of our model

- A battery storage
- Water pump storage
- A photovoltaic panel (PV)
- A consumer
- An electrical network

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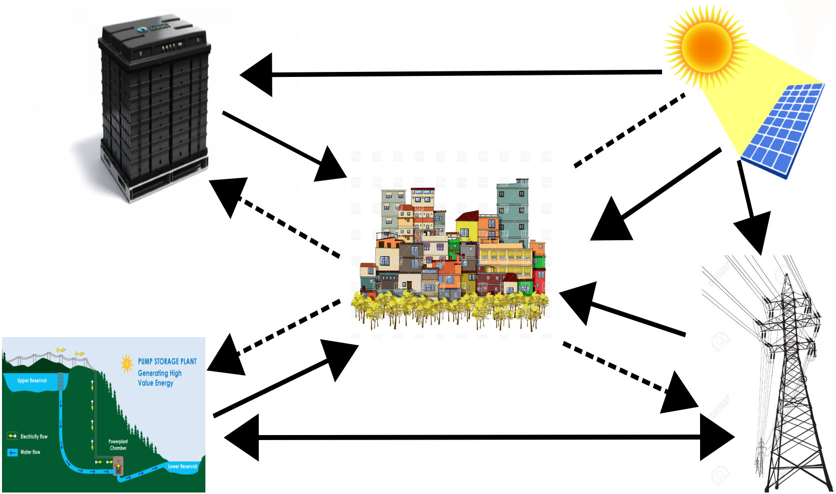

Storage

- The water pump storage is a massive storage element, but has slow response time

- Batteries are for storing smaller quantities of energy, with instant response time

- In order to model those differences in a meaningful way, we need finer time frames (more later)

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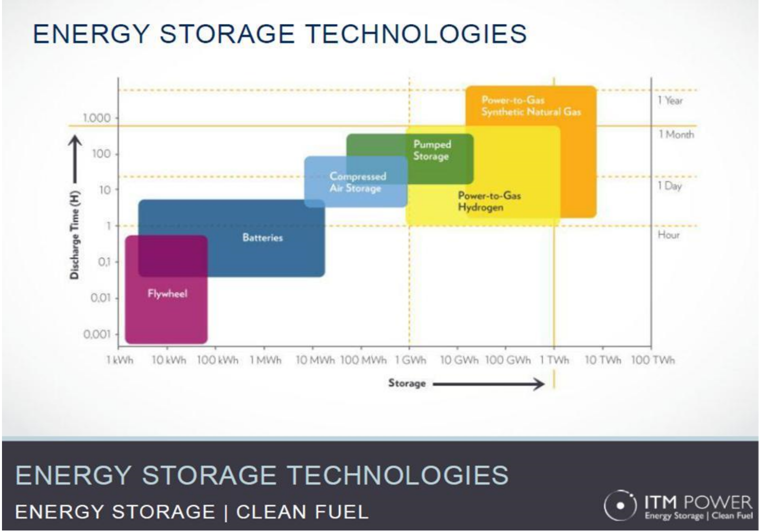
Storage technologies



ENERGY STORAGE TECHNOLOGIES

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ENERGY STORAGE | CLEAN FUEL

ITM POWER
Energy Storage | Clean Fuel

Batteries

$$B_{t+1} = B_t + \alpha_B \overbrace{\left(F_{PV-Battery,t} + F_{Network-Battery,t}\right)}^{\text{into the battery}} \\ - \overbrace{\left(F_{Battery-Demand,t} + F_{Battery-Network,t}\right)}^{\text{from the battery}},$$

with $\alpha_B \leq 1$.

$$F_{PV-Battery,t} + F_{Network-Battery,t} \leq \text{max charge power} \times \Delta T$$
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Water pump storage

$$S_{t+1} = S_t + \alpha_S \beta \overbrace{\left(F_{PV-S,t} + F_{Network-S,t}\right)}^{\text{into the storage}} - \beta \overbrace{\left(F_{S-Demand,t} + F_{S-Network,t}\right)}^{\text{from the storage}}$$

with $\alpha_S \leq 1$, and where β converts electrical energy into water volume.

$$F_{PV-S,t} + F_{Network-S,t} \leq \text{max pumping power} \times \Delta T$$

$$F_{S-Demand,t} + F_{S-Network,t} \leq \text{max turbine power} \times \Delta T$$

In addition,

$$\left| \frac{\partial^2 S_t}{\partial t^2} \right| \leq \Gamma \Leftrightarrow$$

$$\frac{-S_{t-\Delta t} + 2S_t - S_{t+\Delta t}}{(\Delta t)^2} \leq \Gamma_{pumping}$$

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The PV

- We assume energy generated by the PV is random
- We use 4 years of real data from the north of Chile
- The scenarios and their probabilities are constructed via *k*-means
- If the amount generated is higher than expected demand, the microgrid can sell the surplus to the network
- If it is smaller energy must come from other sources, e.g., bought from the network of taken from batteries

$$ProdPV = F_{PV-S} + F_{PV-Bat} + F_{PV-Demand} + F_{PV-Network} - \text{Surplus} + \text{Shortage}$$

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- We face the usual granularity trade-off:
- Too fine-grained and we cannot solve the problem, too coarse-grained and the model becomes meaningless.
- We propose a compromise solution: decision are taken every 15 minutes, and there are three radiation scenarios every day, based on real data.

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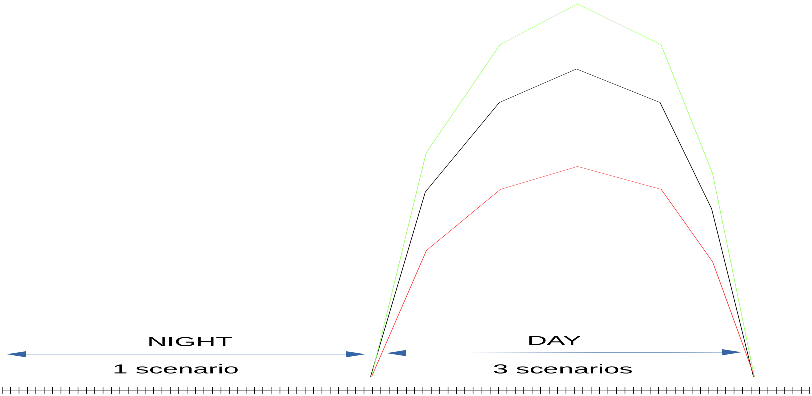
Uncertainty representation



Time series analysis

- We wanted to fit the data into a time series model
- Several options: AR, MA, ARMA, ARIMA, ARMAX, ...
- Dickey-Fuller test indicated stationarity, so we decided for an ARIMA
- Parameter choice was done through RMSE, MAD and MAPE
- The winner was ARIMA$(2, 0, 0)x(1, 0, 1)x24$:

$$Y_t = 1.2131Y_{t-1} - 0.3389Y_{t-2} + 0.9725Y_{t-24} - 0.4202\xi_{t-24} + \xi_t + 497.7$$

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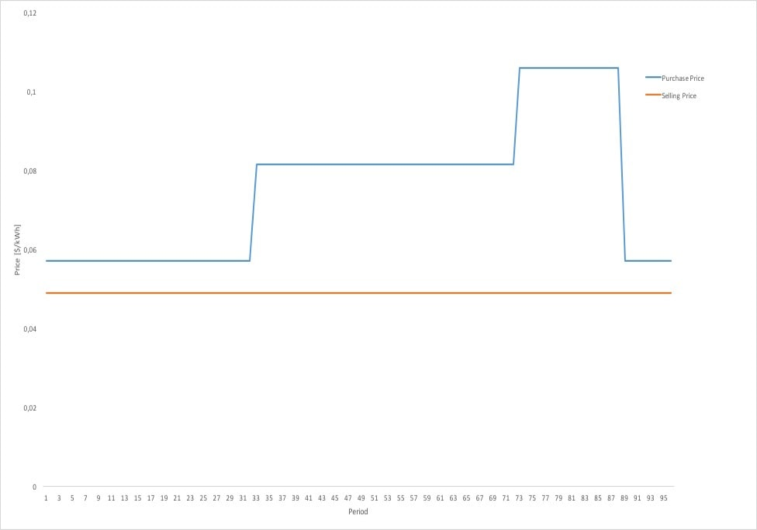
Buying and selling prices



Objective function

$$\min_F \mathbb{E}\Big[\sum_{t=0}^{T}\{(F_{Network-Demand,t} + F_{Network-Battery,t} + F_{Network-S,t}) \times \text{buying price}_t + \text{shortage}_t$$

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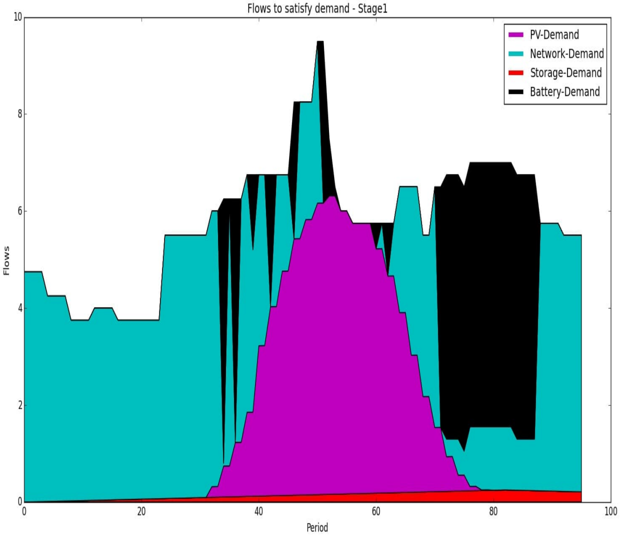
Demand satisfaction - example



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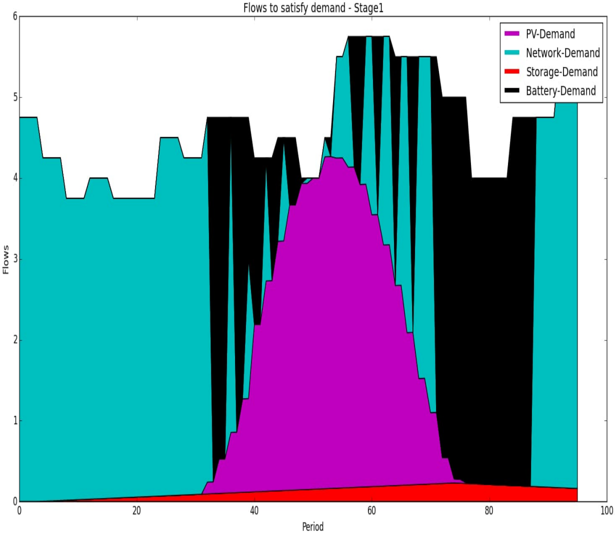

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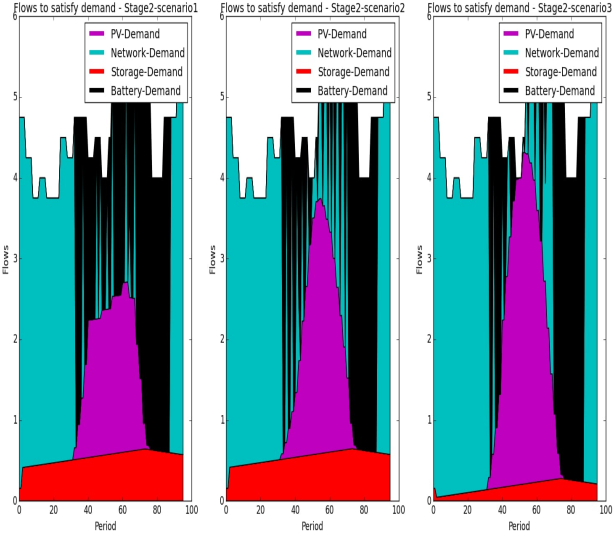

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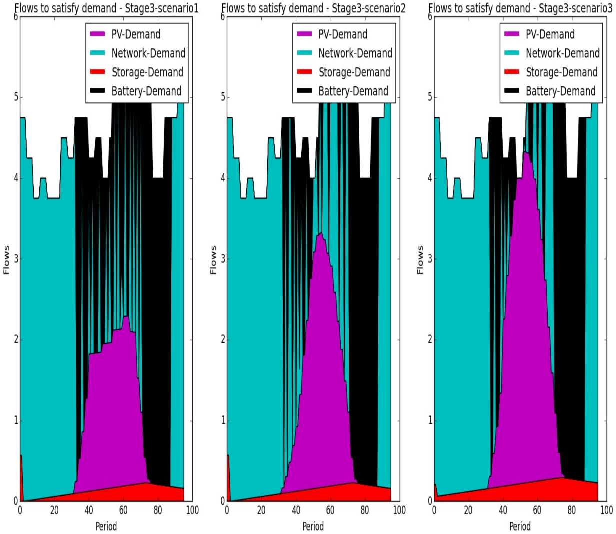

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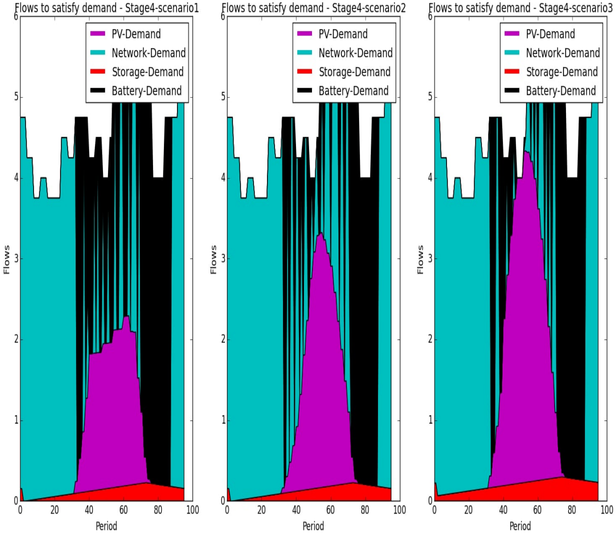

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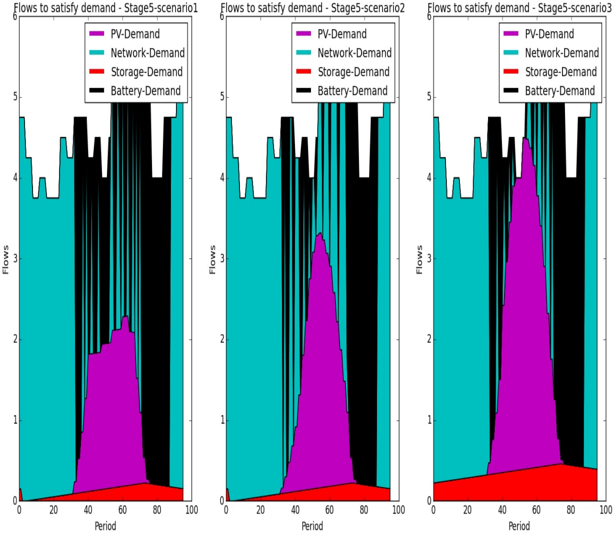

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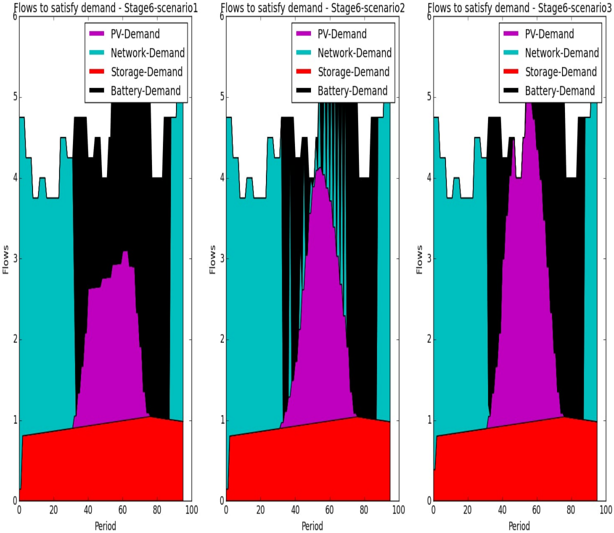
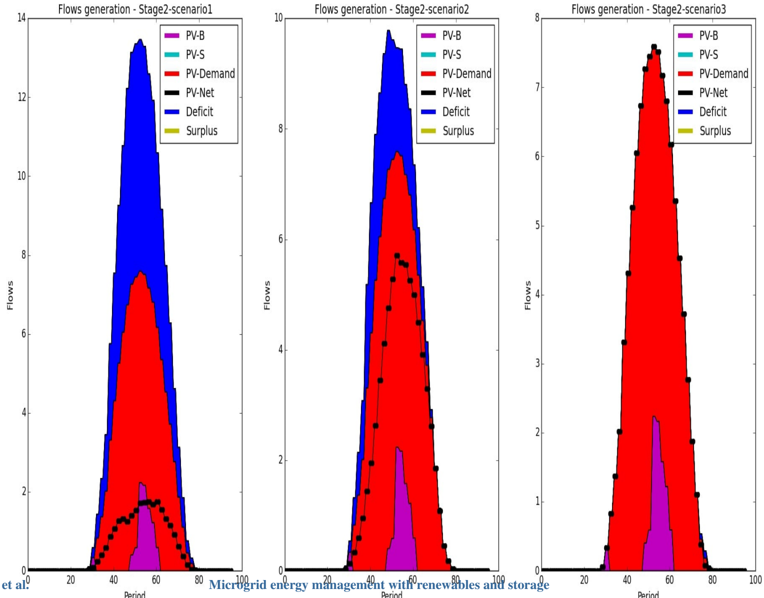
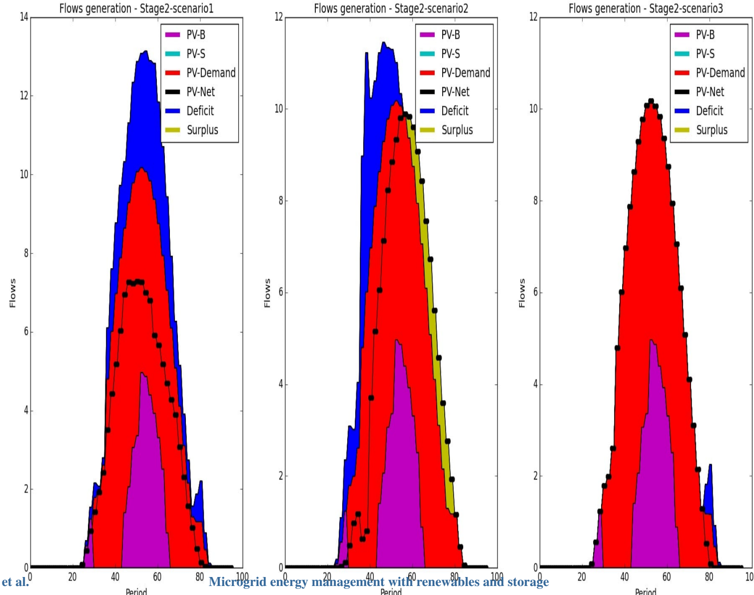


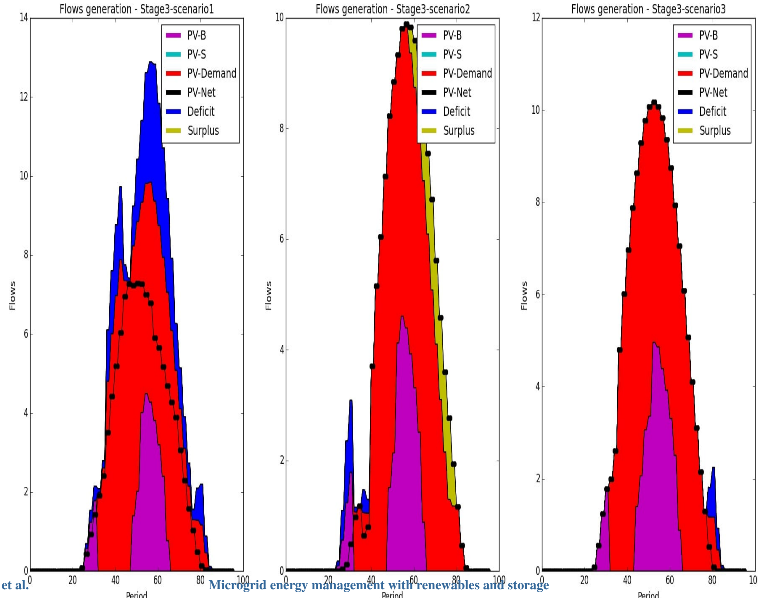
PV destination - August



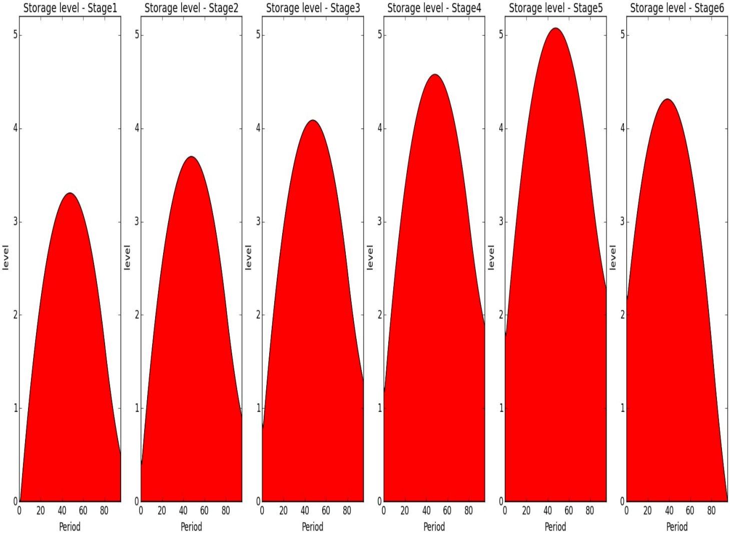
PV destination - December



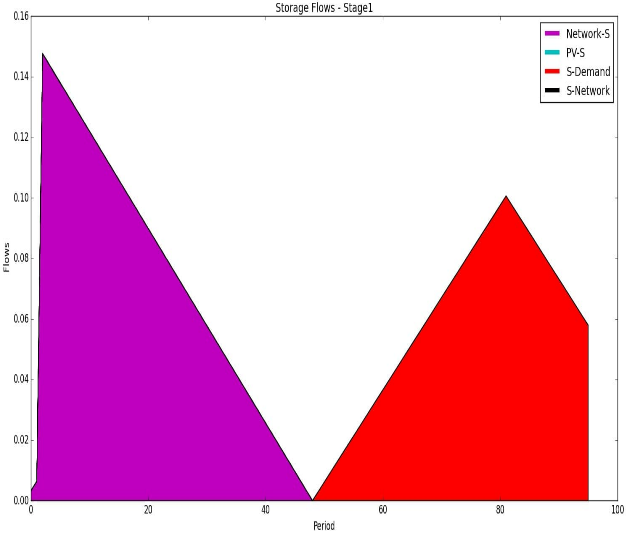
PV destination - December



Reservoir level $S = 0$



Storage flows ($S_0 = 0$)



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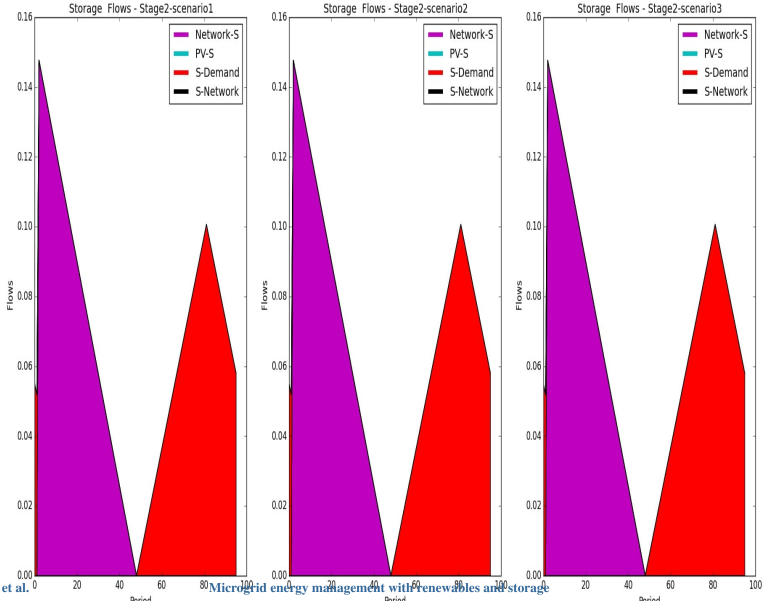

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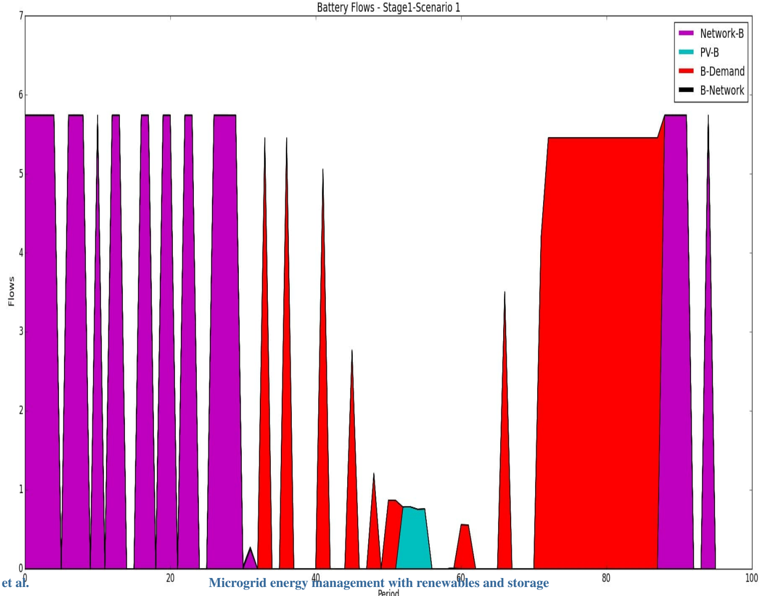

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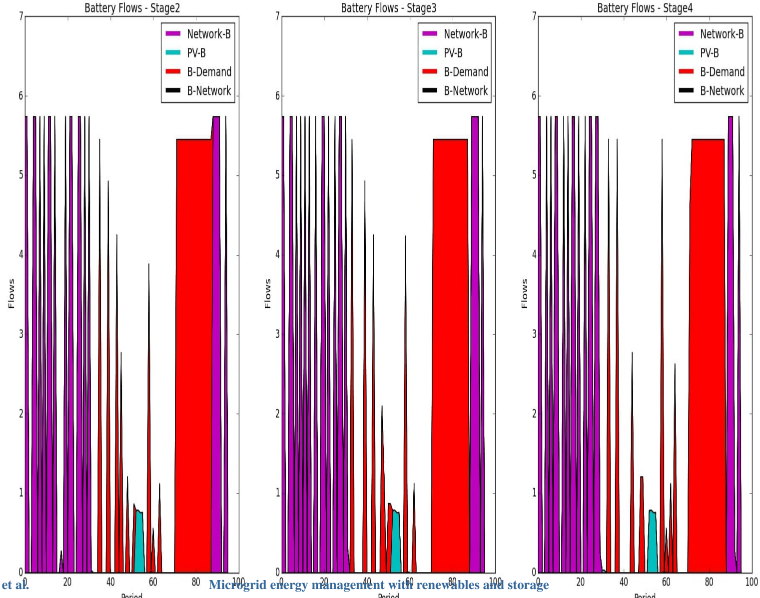

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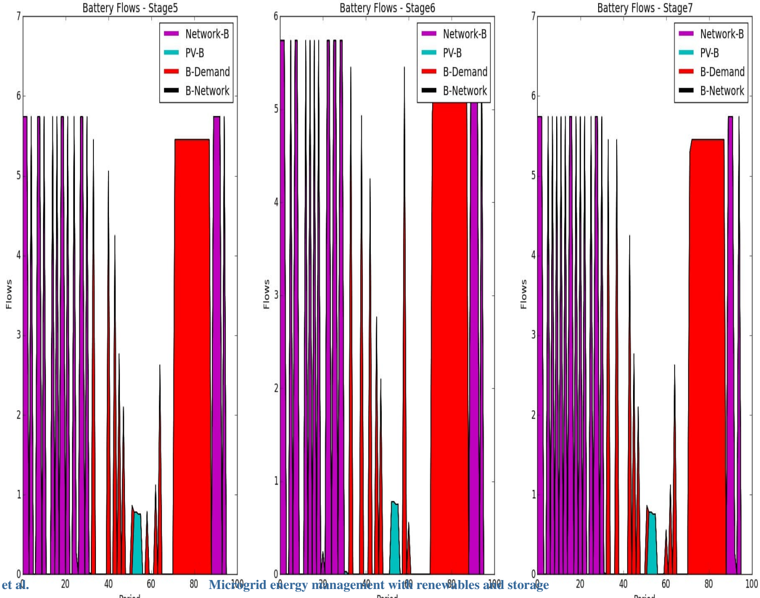
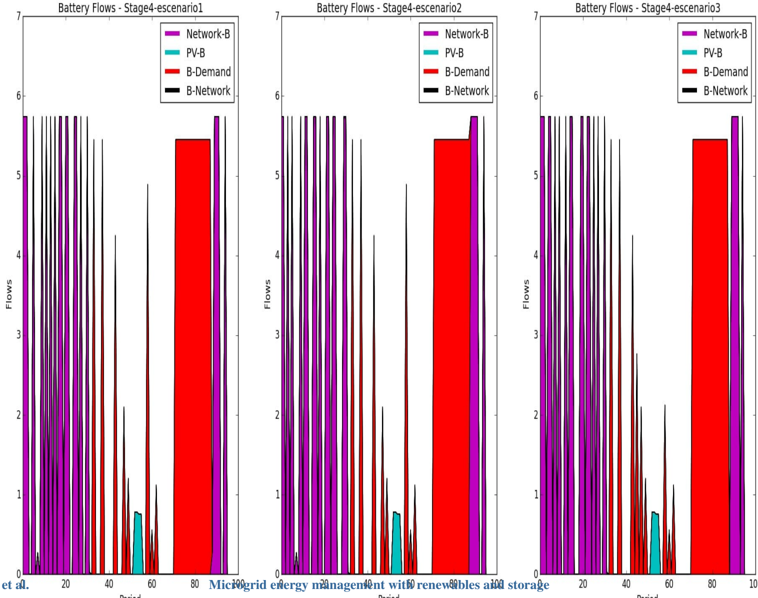


Battery flows ($B_0 = 0$)



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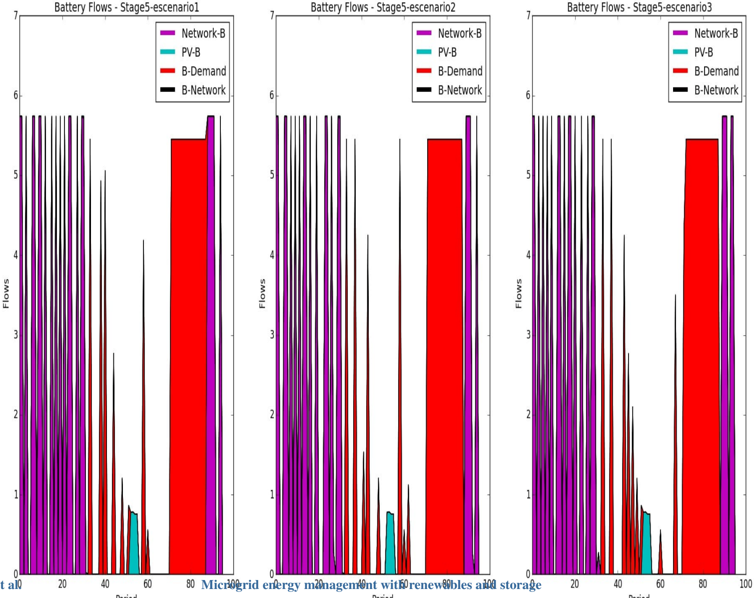

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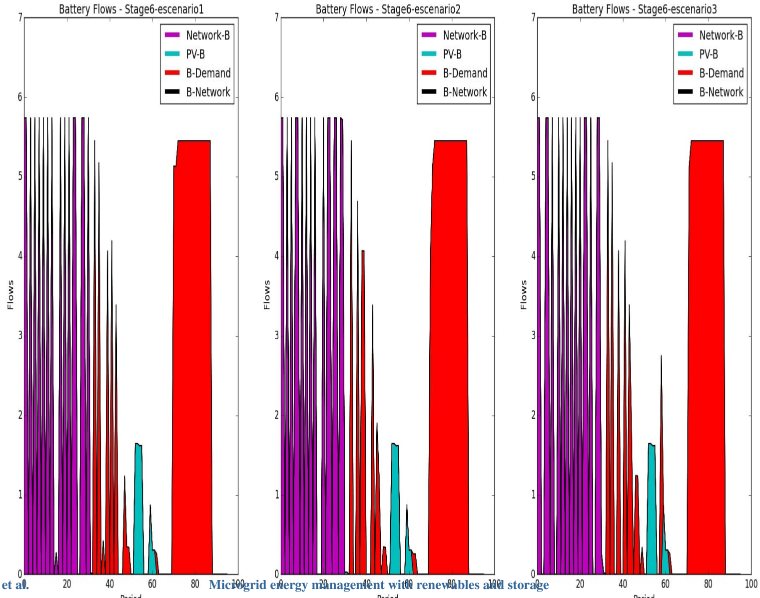
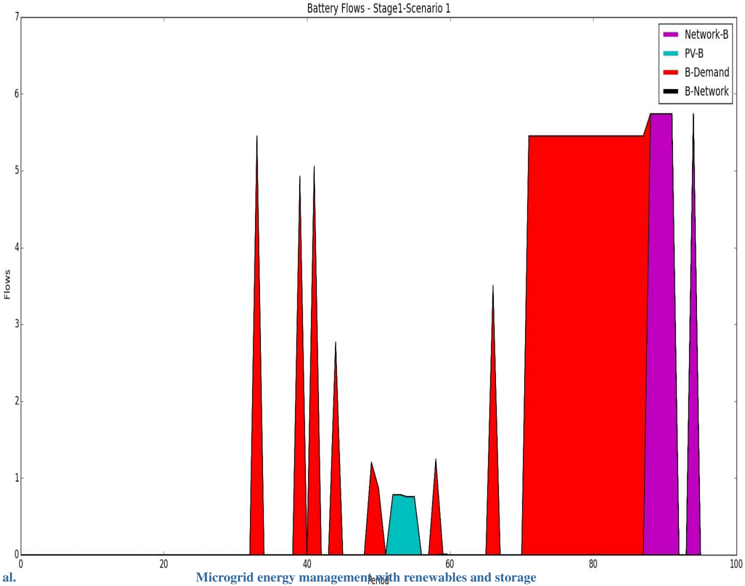
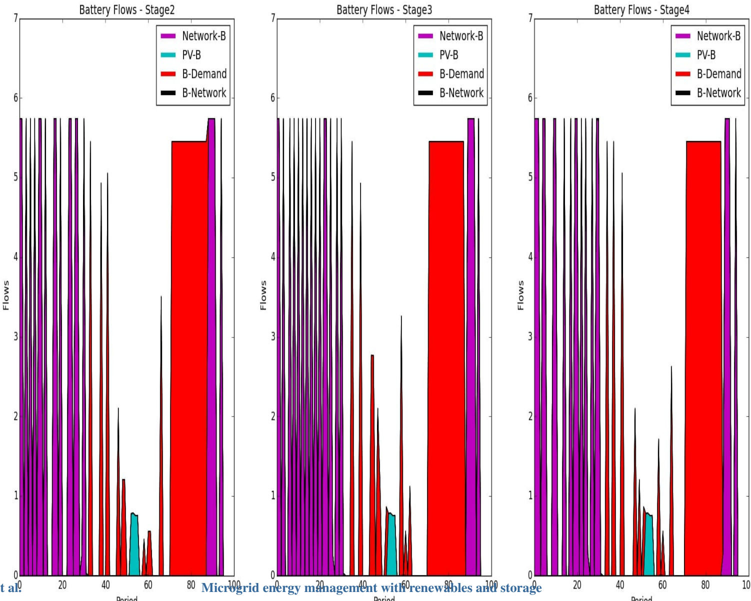


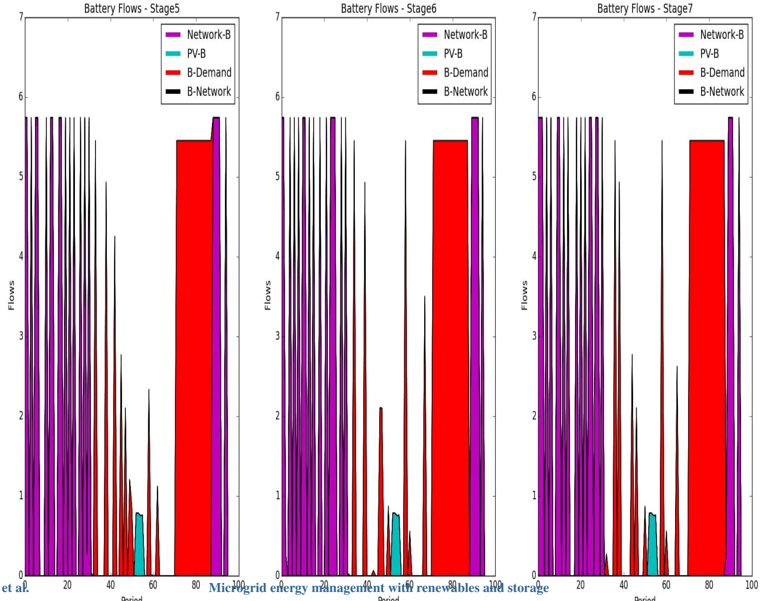
Battery flows (B_0 =max)



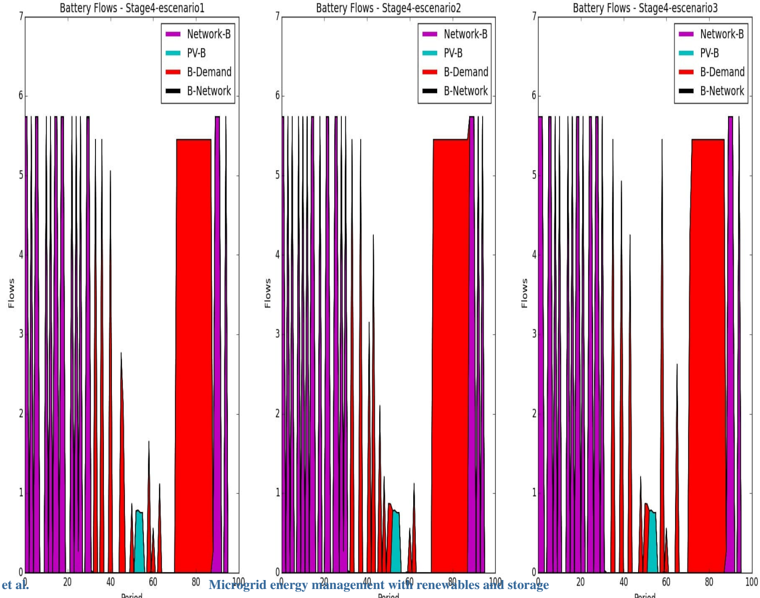
Battery flows (B_0 =max)



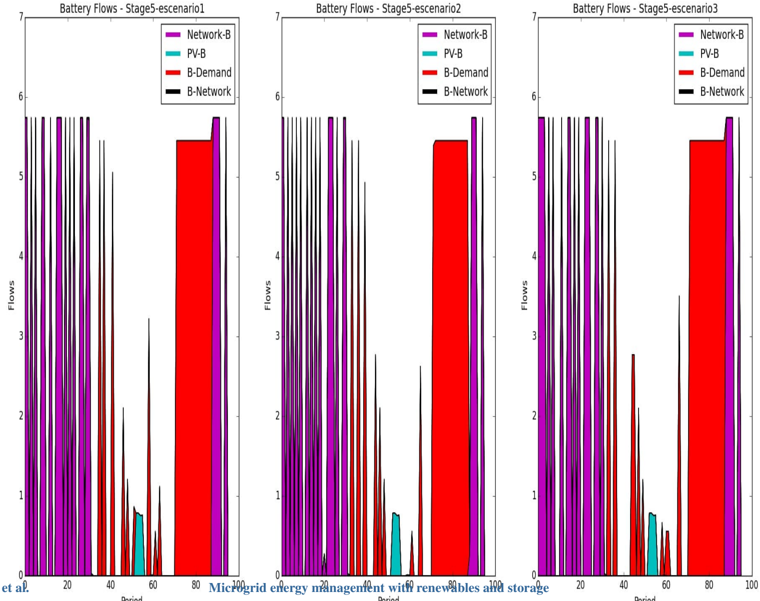
Battery flows (B_0 =max)



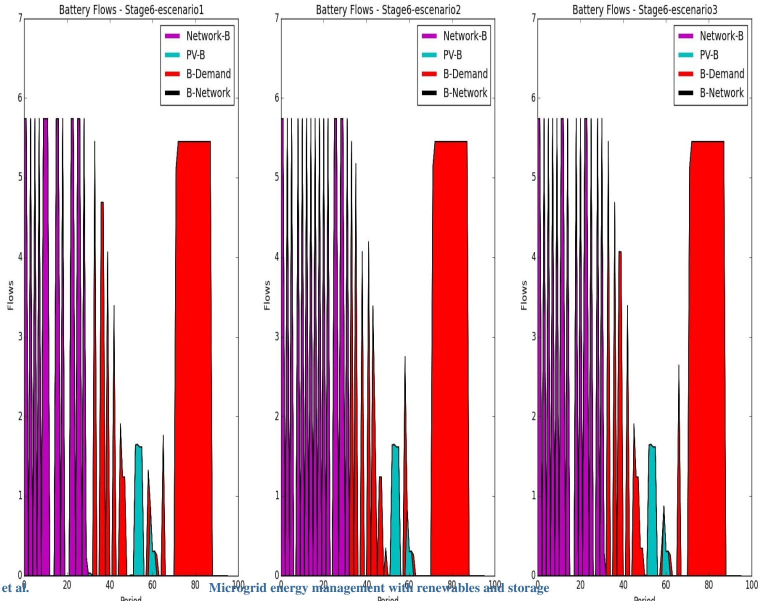
Battery flows (B_0 =max)



Battery flows (B_0 =max)



Battery flows (B_0 =max)



Outline

1. Introduction
2. The model
3. Results
4. Conclusions and future work

Present and future research

- Implement policy evaluation via simulation (important in practice)
- Incorporate risk into the objective function, and study the effect in the optimal policy
- Combine data with forecast to make decisions
- Derive managerial insights about the microgrid operation
- Improve the model with other elements relevant to the microgrid (e.g. wind generation, electrical vehicles, etc)

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Thanks!

Work supported by EDF through PGMO program, project **LASON 2: Centralized and Decentralized Energy Management in a Stochastic Setting**.