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Robust optimisation of the pathway towards a sustainable whole-energy system

A hierarchical multi-objective reinforcement-learning based approach

Doctoral dissertation presented by
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Abstract

This thesis will be awesome

“Pour ce qui est de l’avenir, il ne s’agit pas de le prévoir,
mais de le rendre possible”

– Antoine de Saint Exupéry, Citadelle, 1948

Remerciements

Thank you, thank you, far too kind

Contents

Symbols

Acronyms

PCE	Polynomial Chaos Expansion
SDGs	Sustainable Development Goals
UQ	Uncertainty Quantification

Introduction

Our society In their 2030 Agenda, United Nations have worked on identifying 17 Sustainable Development Goals (SDGs) as a plan of action for society (or people), environment (or planet) and economy (or prosperity) [1].

General introduction to the need of energy transition

How electrofuels will be part of the solution. Here include part of the terminology paper `https://www.frontiersin.org/articles/10.3389/fenrg.2021.660073/full` to clearly set the context and make sure the readers understand what's behind electrofuels and emphasize at the end that in our case, we consider electrofuels as the ones from renewable sources (with a 0-gwp).

From this need, develop a thread like I did in my FRIA application, we need whole-energy system model to give more insights to policymakers

Listing some examples of situations where uncertainties have not been considered and ended up in over-cost/waste of time/waste of..., highlight the need as well to consider uncertainties when we want to advise policymakers.

As the question of policymakers is not only what to do but how to do it, we need to address the optimisation of policies. This would introduce the RL part

Chapter 1

From a whole-energy system model and an uncertainty quantification framework

In this chapter, we introduce the two main tools, not exhaustively of course (because already presented, in Gauthier and Diederik's theses) on which I based my work: EnergyScope and RHEIA/PCE. I'd like too to talk about the case study (Belgian energy system) that will be addressed all along the manuscript but I'm afraid it'd be too many stuff in one chapter. On the other side, I would not dedicate an entire chapter to any of these three parts. What's your opinion?

1.1 EnergyScope: To optimise the energy transition pathway

1.1.1 EnergyScope TD

Presentation of the capacity to model a whole-energy system,with a hourly resolution, and of the main equations of the snapshot model (similarly to what I've done in the electrofuels+UQ paper (`https://www.mdpi.com/1996-1073/14/13/4027`).

1.1.2 EnergyScope Pathway

From snapshot to pathway optimisation, presentation of the main equations to link the representative years, focus on the salvage value (not presented in Gauthier's thesis but well in our Pathway paper)

1.2 RHEIA: To quantify the uncertainties

1.2.1 Uncertainty characterisation

Presentation here of the uncertainty characterisation from S. Moret and adding some parameters specific to the pathway model (e.g. Δ_{change} linked to change speed) or specific to the main case study (e.g. possibility to have nuclear SMR from 2040)

1.2.2 Polynomial Chaos Expansion

Similarly to what we did in the electrofuels+UQ paper (`https://www.mdpi.com/1996-1073/14/13/4027`), presentation of the PCE and Sobol' sequence (which is a more optimised way to explore the ranges of uncertainties, compared, for instance, to random exploration).

1.2.3 Preliminary screening and selection

Similarly to what we did in the electrofuels+UQ paper (`https://www.mdpi.com/1996-1073/14/13/4027`), emphasise that we only consider a limited amount of uncertain parameters to keep a reasonable computation time while capturing the impact of (almost) all the uncertainties.

1.3 Case study: The Belgian energy system

Similarly to what we did in the electrofuels+UQ paper (`https://www.mdpi.com/1996-1073/14/13/4027`),I'd present generally here the case study, much shorter than what Gauthier did in his thesis. It'd be presenting the different sets of resources, technologies and demands.

Here, I could integrate the information on the NED and how important it is to consider it as it represents 10% worldwide (and even 20% in Belgium) of the energy consumption, especially because it is usually a sector that is overlooked in whole-energy system optimisation.

Chapter 2

Electrofuels and uncertainties in a target future year

In this chapter aims at showing the first step of uncertainty quantification and highlight a first insight in terms of impacting parameters. It'd also highlight that depending on the gwp_limit

2.1 From a cost-optimised to a carbon-neutral Belgian energy system: progressive defossilisation

In this section, I'd include the section 2 of the electrofuels+UQ paper (`https://www.mdpi.com/1996-1073/14/13/4027`)(without 2.2 where I presented EnergyScope that I'd include in Chapter 1).

2.1.1 Electrofuels

This section would be as the section 2.1 of the electrofuels+UQ paper (`https://www.mdpi.com/1996-1073/14/13/4027`), where I present more specficially how electrofuels are implemented in the model

2.1.2 Reference Case Study: The Belgian Energy System in 2050

Basically section 2.3 of the electrofuels+UQ paper (`https://www.mdpi.com/1996-1073/14/13/4027`), where I present more specficially how electrofuels are implemented in the model where I present what a cost-optimised (without gwp-constraint) Belgian energy system would look like

2.1.3 A step by step defossilisation of the snapshot system

As in section 2.4, quickly show how we implement the defossilisation without having an entire pathway.

2.2 Results

Similar to Section 4 of the electrofuels+UQ paper (`https://www.mdpi.com/1996-1073/14/13/4027`). There'll be work to generate up-to-date results as the model evolved (no more FC_cars but BEV, for instance)

2.2.1 Statistical analysis of the cost

2.2.2 Critical parameters

2.3 Discussion and perspective with the literature

Similar to section 5.1 of the electrofuels+UQ paper (`https://www.mdpi.com/1996-1073/14/13/4027`)

Chapter 3

From a perfect foresight to a myopic optimisation of the pathway

In this chapter, I highlight the advantages of the myopic pathway, the methodological adaptations needed to have a myopic optimisation from EnergyScope Pathway perfect foresight and detail the difference with the perfect foresight for the case study.

3.1 Why and how myopic

Besides the fact that it is a necessary framework for the application of RL, explain here why it is interesting, as is, to consider myopic optimisation (time saving, more appropriate to mimic policymakers' shortsightedness, etc.)

Detail the little tweeks to go from a perfect foresight to a myopic optimisation, in terms of implementation.

3.2 Case study and results: Belgian energy system under CO_2 trajectory

3.2.1 Case study

Question to HJ and FC : J'hésite sur le cas de référence pour la comparaison en termes de trajectoire CO_2. Voici ce à quoi je pense:

1. Comme ce qu'on a présenté dans le papier Pathway, une décroissance linéaire entre les émissions de 2020 et la neutralité carbone en 2050

2. Sur base du budget CO_2 identique à celui de la décroissance linéaire (1.9GtCO_2), imposer au myopique la trajectoire CO_2 issue de l'optimisation perfect foresight. Dans cette option, il y a deux sous-choix:
   - Imposer la neutralité carbone en 2050, comme dans le cas 1.
   - Ne pas imposer la neutralité carbone en 2050
3. Sur base du budget CO_2 que je donne implicitement comme objectif à mon agent (1.2GtCO_2), imposer au myopique la trajectoire CO_2 issue de l'optimisation perfect foresight. Dans cette option, il y a deux sous-choix:
   - Imposer la neutralité carbone en 2050, comme dans le cas 1.
   - Ne pas imposer la neutralité carbone en 2050

Perso, je choisirais de me rapprocher le plus possible de ce que je fais ensuite avec l'agent. Du coup, ce serait le cas 3 sans imposer la neutralité carbone 2050. Dans ce cas, pour l'avoir observé, le modèle n'atteint pas la neutralité carbone.

Quel est votre avis sur la question?

Define the case study and the CO_2 trajectory.

3.2.2 Results and comparison with Perfect foresight

3.2.3 Discussion and perspective with the literature

Chapter 4

Reinforcement Learning CO_2-policy robust optimisation

4.1 Reinforcement learning fundamentals

As RL is framework that is not really applied to the optimisation of the whole-energy system transition, I find it necessary to introduce the general concepts of reinforcement learning and say that, even if it is usually used in other fields, there is a point to use it here.

4.2 Definition of the actions, states and rewards

After pointing out that the environment is basically the EnergyScope myopic model at the different steps of the transition, define the actions, the states as well as the shape of the reward.

4.2.1 Actions

4.2.2 States

4.2.3 Reward

4.3 Uncertainties in the learning

Remind here that uncertainties considered in the learning of the agent are those presented in Chapter 1 and already applied and screened in the work/results presented in

Chapter 2. Present as well how we affect the value of the parameters based on the value of the sample.

4.4 Results

4.4.1 Training

Here present results RL-oriented (actions, states, reward)

Then, present results energy system-oriented (installed capacities, costs, generation)

4.4.2 Testing

See how the different policies saved successively during the training behave when facing to new samples. This way, we can pick an optimal policy (the one giving the maximum average (or another metric) reward).

We then compare the results of RL with the perfect foresight-TD deterministic and the perfect foresight-monthly with uncertainties (by setting the actions of the agent as variables in these two optimisations). The comparison would go over different aspects:

- Over-cost
- Over-change, a bit like what Paolo defined as design error/change (in terms in consumed resources, installed capacities,...)

Conclusions

I took here the same sections as in Gauthier's thesis

Thesis contribution

Insist here on the methodological added value of the thesis

Application outcomes

What this new methodology has brought over when applied to the case of Belgium

Recommendations and guidance

What to do then for policymakers, how to use the tool

Perspectives

List the future works to build upon the thesis

Bibliography

[1] United Nations, The 17 goals, `https://sdgs.un.org/goals`, September 2015 (accessed June 7, 2023).