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autumn: A Python library for dynamic modelling of captured CO_2 cost potential curves

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Summary

The tool autumn was developed to address the characteristic uncertainty of an evolving technological development in carbon capture in conjunction with different portfolio scenarios. It consists of a dynamic data pipeline to create a geographically resolved cost and potential distribution of captured CO_2. It overcomes two central challenges of using solutions offered by other authors: First, users can specify the geographical scope and thus align the cost potential characteristics to the model and research specific scope. Secondly, dynamic technology parameters can be specified in order to describe uncertain political and societal choices in the studied models. autumn provides different degrees of granularity in its interfaces, so that modellers can flexibly adapt the library to their needs.

Statement of Need

In the field of energy systems analysis, models are used to assess the viability of different technologies, policies and network configurations (Scholz, 2012).
Recent research focuses on the interconnection and interactions between energy demand sectors like transport and industry with electricity grid feed-in and balancing technologies (Brown et al., 2018). These models rely on data from nowadays technologies and energy demand.

One of the important challenges in the field is the assessment of developing technologies, especially at the boundary of the electricity sector with the transport, heat and industry sectors. CO_2 capture has been widely demonstrated in laboratory and pilot plant contexts but is yet to be scaled up to reach significant market shares (Bui et al., 2018). Information of long-term market potential and cost is uncertain. This uncertainty is often hard to reliably integrate into the models because it arises in different components of the technological cost and potential estimations.

Carbon dioxide plays a key role as an educt in synthetic fuel production processes, which are an integral part of most low carbon or carbon-neutral sector coupled energy systems described in literature (Ruhnau et al., 2019). Decarbonization of the energy system and industry roadmaps outlined in plans such as the European Green Deal (European Comission, 2019) imply a reduction of highly concentrated CO_2 sources. These facts motivate the detailed description of cost and potential of CO_2 sources across different temporal and geographical resolutions e.g. in order to assess the optimal location of synthetic fuel refineries.

Researchers currently have the following options to include carbon capture cost and potential in their analysis: One is to estimate potential from emission report databases such as (EEA, 2019) along cost values from the literature and disregarding technology-specific characteristics such as capacity factors of the emitting facility and different carbon capture technologies or investment characteristics (Von der Assen, 2016). A second approach is to assume equivalent techno-economical conditions across the whole system boundary using data from research such as Naims (2016). This second approach is depicted by a vertical and a horizontal line respectively in Figure 1.

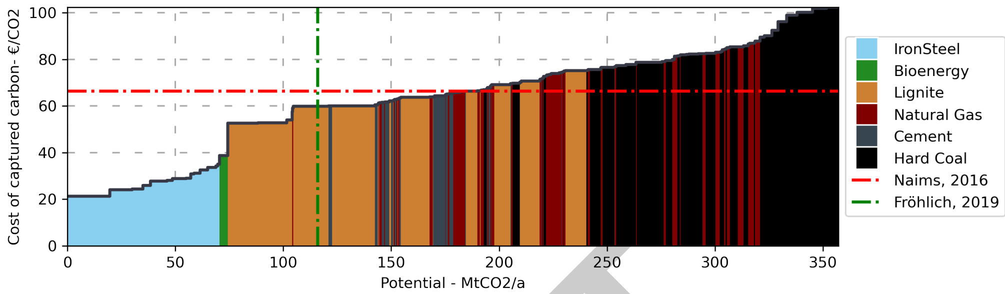

Figure 1: Marginal cost estimates for capturing CO_2 from different industries in Germany against exemplary reference cost (Naims, 2016) and potential as they are used in (Fröhlich et al., 2019)

The demand of high resolution data in sector coupled energy systems modelling can be exemplified by the PyPSA-Eur-Sec Project, a model with all of Europe in a sub-national to national scope. The model documentation states that CO_2 from captured sources is considered as if it was coming from a single node for all of Europe. This could be improved by integrating `autumn` in the model pipeline.

Neumann & Brown (2021) explicitly call for a more detailed description of sector coupling in the context of near optimal feasible solution space analysis of energy system models. In general, evaluating placement choices for synthetic fuel refineries requires a higher geographical detail of CO_2 availability and cost characteristics.

Functionality

`autumn` consists of a flexible data pipeline that can be used to calculate cost potential curves of captured CO_2. It allows their users to configure the calculation steps to include the assumptions of their own projects. Additionally, it allows the post processing of the produced datasets to resolve different geographical and technological scopes. The design of the project is modular to allow complex model building. The general architecture of the tool can be observed in Figure 2.

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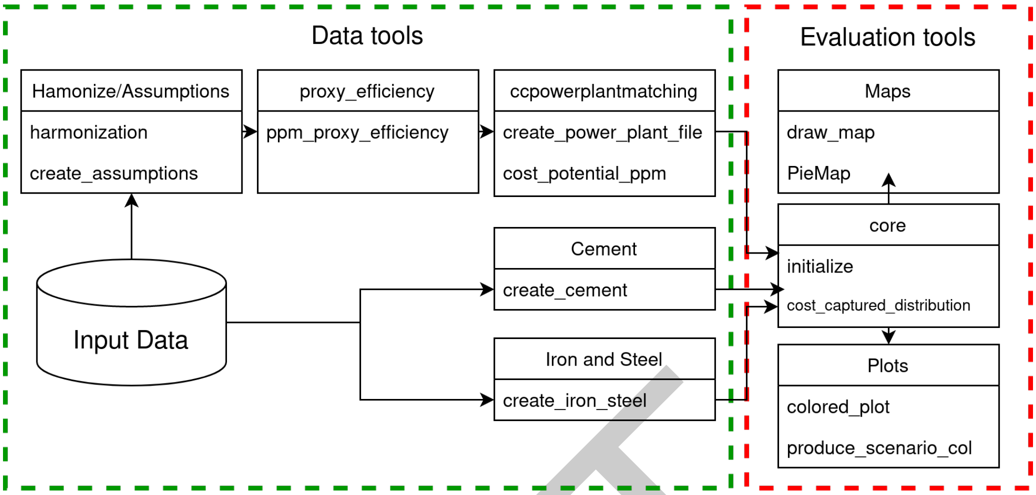

Figure 2: There are two main target users: model builders and data analysts. The data tools ease creating new pipelines, the evaluation tools offer Visualization options.

`autumn.scripts.harmonize`

Having ways of integrating uncertainty of the cost is one of the key features of the tool. Cost of carbon capture has investment, operational and management components. Instead of a monolithic inclusion of the cost, it is opted to separate these values in order to facilitate the inclusion of variations of these components. The harmonization script is used to harmonize values from sources reporting in different formats and units. The script `autumn.scripts.assumptions` is provided to perform a statistical aggregation of the values to create upper and lower limits with a given level of confidence.

`autumn.scripts.ccpowerplantmatching`

This, along with the `cost_of_carbon_capture_cement` and `cost_of_carbon_capture_iron` scripts, is used to create homogenized geographically distributed carbon capture cost and potential datasets. They use the output values of the harmonization script as input. The powerplantmatching tool (Gotzens et al., 2019) paired with a regression model for data completion is used as a base for the creation of a power plant distribution. `autumn` does not depend on this specific data source, a different one can be used as long as the output is consistent with the inputs of the curve production section. The configuration files allow for a wide range of customization options of these scripts.

`autumn.core`

The main function of `autumn` is to use the input data to create datasets with different characteristics, such as different aggregation levels, country filtering and source filtering. The core module facilitates these tasks with a set of functions. The data evaluation section of the framework entices the core module and the ones for creating plots and maps. Figure 3 exemplifies `autumn` results along the geographical scopes of Europe, Germany and the federal state of North Rhine-Westphalia.

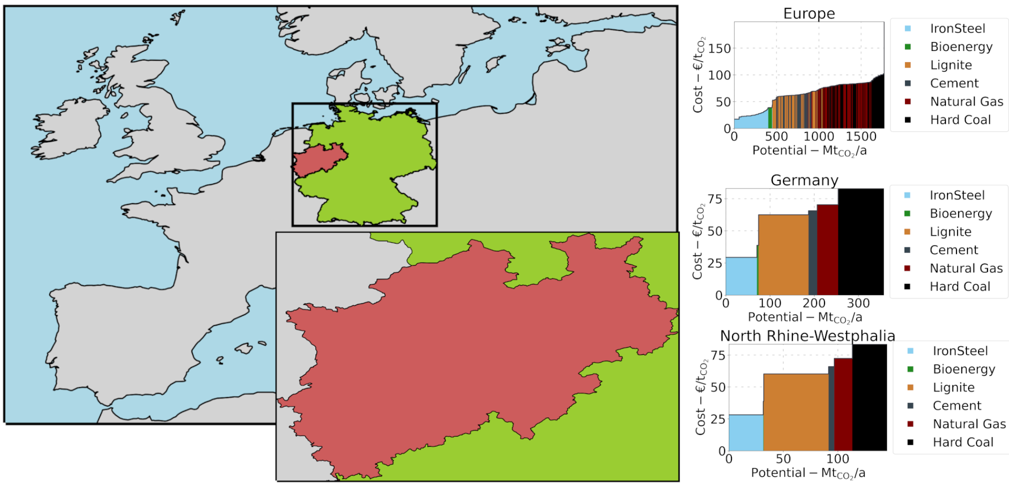

Figure 3: The API can calculate potentials at different geographical levels

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