DREAM
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GREEN REFORM

Technology catalogs in GreenREFORM

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1. Introduction and overview

So-called technology catalogs contain technical and economic information about a collection of technologies. One goal of the GreenREFORM model is to directly integrate the information contained in such catalogs in the model. The memo highlights a series of issues related to integrating the current technology catalogs in GreenREFORM. These issues are solvable by either constructing new technology catalogs or supplementing the current catalogs with additional assumptions. The hope is that this memo can provide a basis for discussion on the right approach moving forward.

This first section gives an overview of relevant technology catalogs and the current integration status. In the following section, we give more details on how each catalog is used in GreenREFORM. We conclude the note with a detailed example on which additional assumptions we make in order to integrate a technology catalog in the GreenREFORM model.

A crucial part of the green transition of the economy is the development and use of new technologies that help to reduce emissions, either directly or indirectly through energy use changes. Information on such technologies is often left out of economic models, which can distort the effects of e.g. a greenhouse gas tax. Information on new technologies is contained in so-called technology catalogs, which detail technical and economic information about a collection of technologies. A goal of GreenREFORM is to use this information as directly as possible in the model.

Many different actors produce technology catalogs, and it is therefore relevant to clarify which technology catalogs that should be integrated into GreenREFORM. We use primarily two criteria, namely that 1) the catalogs should be non-overlapping and 2) the catalogs should come from an official source, such as a government ministry or agency (in practice, most of the data that we use come from the Danish Energy agency), or from academic work requisitioned by a Danish ministry or government agency. However, the model is set up such that a model user can add more technologies (or entire catalogs). There are also areas where it is known that the data we are currently using could be expanded and improved; this is for instance the case with the technology catalog used for agricultural emissions.

In relation to the GreenREFORM project, two methods have been developed to integrate technology catalogs into large-scale CGE-models, namely:

End-of-pipe abatement (Stephensen et al., 2020): This handles technologies that reduce emissions from some source at a cost, without affecting the rest of the production function. This includes agricultural non-energy emissions-reducing technologies as well as potentially carbon capture and storage solutions. For this method to work, the following data is required for each technology:

1. An emissions base, that the technology can reduce (this could for instance be agricultural emissions related to manure management)
2. A potential, i.e. the share of the emissions base that the technology can reduce
3. A unit cost, i.e. what does it cost to reduce emissions by e.g. 1 ton

Input-displacing abatement (Berg et al., 2020; Beck & Kirk, 2020)**:** This method handles technologies that affect the production function of the firm, and therefore the rest of the economy. This could for instance be a more energy-efficient machine used for an industrial process. This machine reduces the demand for energy at some other cost to the firm (usually in the form of a more expensive machine). Since energy from fossil fuels give rise to greenhouse gas emissions, input-displacing technologies will in many cases also reduce emissions. For this method to work, the following data is required for each technology:

1. An input base that the technology can reduce (this could for instance be gas used for industrial processes)
2. A potential, i.e. the share of the input base that the technology can reduce.
3. A unit cost, i.e. what does it cost to reduce use of the input by one unit
4. (optional): Information on other types of inputs that increase when the technology is used (this could for instance be an increase in use of electricity if the new machine runs on electricity instead of a fossil fuel, or additional labor required to operate the new machine)

Table 1.1 gives an overview of existing non-overlapping technology catalogs that we believe could plausibly be integrated into GreenREFORM. The table also gives an overview data availability and a status on which catalogs are currently integrated into GreenREFORM.

Table 1.1
Overview technology catalogs in GreenREFOM

#	Scope	Source	Status - data	Status - model
1	**Industry:** Industrial energy savings	• Model data obtained from The Danish Energy Agency	Data is available. No regular update.	Integrated
2	**Industry:** Industrial process heat	• Technology catalog published online by The Danish Energy Agency	Data is available and regularly updated.	Integration is possible
3	**Households:** Buildings	• Andersen et al. (2020)	Data is available. No regular update.	Integration is possible
4	**Households:** Heating source	• Technology catalog published online by The Danish Energy Agency	Partial data is publically available.	Full integration currently not possible
5	**Households:** Electric appliances	• Data from ElModelBolig, obtained from The Danish Energy Agency	Data is available. No publicly available updates.	Integration is possible using a simple approach
6	**Agriculture:** non-energy emissions	• Danish Energy Agency (2020) • Dubgaard og Ståhl (2018)	Data is available. No regular update (of Dubgaard and Staahl data).	Integrated (part of agriculture module)
7	**Transport and power-to-x**	• Data from the Danish Energy Agency's Alternativ Drivmiddelmodellen (ADM) published online (ens.dk) • The Danish Energy Agency's technology catalogue for the production of renewable fuels published online (ens.dk)	Data is available. ADM not updated. Technology catalogue is updated regularly, but does not contain emission coefficients.	ADM is integrated (part of transport module)¨ Integration of technology catalogue is possible

Source: Own illustration
Note: Technology catalogs published by The Danish Energy Agency can be found at https://ens.dk/service/fremskrivninger-analyser-modeller/teknologikataloger.

There are some challenges related to this list of technology catalogs:

- The catalogs of table 1.1 are non-overlapping, but not exhaustive. For instance, there are no catalogs that cover the public sector and non-heating energy used by the service sector. This is an area where there is room for improvement in the future. In the following, we focus on the catalogs mentioned in table 1.1.
- In some instances, data is publically available. In other instances, we have obtained the data directly from the source; in many cases from The Danish Energy Agency. In yet other cases, we do not currently have access to data that can be integrated into the model.
- Some of the catalogs are not regularly updated. This is not an issue for developing the model, but over time the catalogs become outdated. This means that in the absence of updates to the catalogs, the properties of the GreenREFORM model will also become outdated.
- Even when data is available, it is often necessary for the GreenREFORM model group to make additional assumptions in order to make the data fit within the model framework. This work is labor-intensive, and the quality of the results rest on the quality of the assumptions made; it is likely that higher-quality assumptions could be made by those who construct the technology catalogs. Moving forward, it would therefore be a great benefit if new versions of the technology catalogs would be on a form that more easily fit into the GreenREFORM framework. Key to this would include ensuring that technology catalogs:
  - Are disaggregated on the same sectors, purposes, and energy types as GreenREFORM
  - Explicitly describe technology potentials (and perhaps different potentials at different costs) and time before technologies are fully adopted
  - Describe the input-mix of technology costs (e.g. how much of costs are technology capital, how much is energy, how much is labor costs etc.)
  - In some cases, it would be useful to have a more well-specified baseline against which technology catalogs work.

In section 2, we describe the specific challenges that we face for each individual catalog. In section 3, we illustrate the kinds of assumptions that we make to fit the data on industrial energy savings into the GreenREFORM framework.

2. Technology catalog status

In this section, we describe the status for the different technology catalogs. Focus is on the availability of data and the status for integrating the catalogs in the model, but in order to address these issues, we also touch upon issues of modelling

Before we describe the individual catalogs, we note two challenges related to integrating the existing technology catalogs. These challenges apply to several of the catalogs described in this section:

Lack of potentials: Some catalogs do not specify potentials for the technologies. Potentials can be hard to estimate, since in some sense, it is always a question of potentials *at what cost*. As an example, it would be technically possible to heat up all houses in Denmark using heat pumps. However, for some share of houses, this would probably be prohibitively expensive, not least in the short run. This may help explain why potentials are not always specified in technology catalogs.

One way to use such catalogs anyway is to augment the catalog with an expert judgement on baseline technology adoption over time. In this way, it is possible to calibrate costs and potentials in such a way that the expert judgement adoption does in fact take place. In essence, this means that the expert judgement is used to back out potentials at given costs. This still allows for the *marginal* technology adoption as a response to a shock to be controlled by the model.

To the best of our understanding, this is in essence how these catalogs are used in, e.g., the IntERACT model of The Danish Energy Agency (ENS). Although in practice, these baseline adjustments are combined with expert judgments to ensure plausible transition. Given an expert judgement on baseline adoption, it would also be possible to employ this approach in GreenREFORM.

Energy savings measured in terms of general energy demand rather than specific fuels:

Energy is always used for a specific purpose, e.g., room heating, industrial processes or transportation. At the micro level, a firm will often use only one energy input to provide, e.g., room heating. However, at the macro level, a sector will often use a combination of energy inputs for a single purpose. In the GreenREFORM model (as well as the model framework of the Danish Energy Agency), these distinct energy inputs combine to an aggregate, e.g., energy for room heating, that is used in the production function. Likewise, for households, the nested utility function includes a nest that aggregates different energy inputs.

The technology catalogs of the Danish Energy Agency, tend to describe energy saving potentials at the aggregated level, i.e., not at the energy input level. For instance, the catalog may give the savings potential for room heating energy in a sector, but not how this potential is distributed among the energy inputs used for room heating. This can reflect a lack of information: It is much harder to collect data on the joint distribution of energy savings and energy inputs than on the marginal distribution of energy savings. An example may clarify: Using information on how many windows can be replaced with new, energy saving windows, it is possible to estimate how much room heat can be saved. It takes additional information to calculate out how many of those windows that can be replaced are located in houses that are heated by, e.g., gas, oil and central heating, respectively.

However, this lack of information presents a modelling challenge. There are essentially two options:

1. Model energy savings directly as savings of the energy aggregate, e.g., room heating.
2. Assume a joint distribution of energy savings and energy input types and model energy savings of each individual energy input type

Model 1 does not require additional data, but can produce unfortunate model implications. An example may clarify: Assume that there is a potential for energy savings of room heat of 10% and that 50% of room heating comes from district heating and oil, respectively.

- Consider now a scenario where a tax on oil makes the energy savings profitable. This reduces energy demand by 10% by reducing oil demand by 20%, while leaving district heating demand unaffected.[1]
- Consider now a second scenario, where a tax on district heating reduces energy demand by 10% and district heating demand by 20%, while leaving oil demand unaffected.

These two scenarios are both realistic, given that we only know that heating energy can be reduced by 10%. However, they cannot, by definition, both be true. In the first scenario, the implicit assumption is that all energy savings take place in houses heated by oil. In the second scenario, the implicit assumption is that all energy savings take place in houses heated by district heating. However, if both were to be true, the potential for energy savings is in fact 20%, not 10%, as stated by the data.

Model 2 does not exhibit this feature. However, it does require an additional assumption on the joint distribution of energy savings and energy input types.

In GreenREFORM, we opt for the model 2 approach. This means that we add an additional assumption on the joint distribution between technologies and energy inputs.

2.1 Industrial energy savings

The data on industrial energy savings originates in a catalog compiled by the consultancy COWI for The Danish Energy Agency (ENS) (COWI, 2015). ENS has modified and updated this data in a number of ways for use in the model framework of ENS, the TIMES model. GreenREFORM has obtained this model dataset from ENS. ENS is in the initial phase of formulating a project that would aim to update the 2015 data.

The currently available data contains information on costs and potentials related to reducing industrial energy use. The costs and potentials vary by sector and by purpose.

In order to make the catalog suitable for use in GreenREFORM, several adjustments have been made. These are described in more detail in section 3 and include:

- A mapping of potentials from the sectors used by ENS and the national accounts sectors used by GreenREFORM
- A mapping of potentials from the purposes used by ENS to the tax-related purposes used by GreenREFORM

[1] In practice, if the two inputs are not perfect substitutes, district heating demand will also be affected, but we abstract from this in the current example.

- A mapping of potentials from general "energy savings" to specific fuels, as discussed in the introduction to section 2

This adjusted version of the dataset is integrated into GreenREFORM using the input-displacing abatement method described in section 1.

2.2 Industrial process heat

ENS recently published a catalog for industrial process heat decribe technologies that can reduce the use of energy used to produce industrial process heat. The catalog contains information on a range of technologies, including costs, current use and maximum potential. This catalog is possible to integrate into GreenREFORM using the input-displacing abatement method. However, a couple of additional assumptions are required, including:

- The potential of some of the technologies in the catalog overlap. This can be handled using the method described in Beck & Kirk (2020).
- Some technologies imply that one type of energy is switched out with another type. These switches are not always well-described in the catalog data, but must be inferred from the accompanying documentation.
- A mapping of potentials from general energy savings to specific fuels, as discussed in the introduction to section 2

The industrial process heat technology catalog has not yet been integrated into GreenREFORM.

2.3 Heat savings of households

Households can reduce their need for room heat by investing in energy-saving measures such as installing additional isolation or new, energy-efficient windows. Savings potentials and costs are available as a supplementary dataset to a recently published paper (Andersen et al., 2020). It is possible to integrate this data into the GreenREFORM model. Two caveats apply:

- This catalog does not describe which specific energy input types that can be reduced. We add assumption about the joint distribution of energy types and energy savings, as described in the beginning of section 2.
- There are two types of potentials and costs described in the data, namely "marginal" (the potential and cost for those who do not have existing energy-saving capital that they are still writing off) and "full" (those who are not currently undertaking an investment). Over time, the entire "full" potential becomes available at the "marginal" cost. Integrating this directly should be possible as a minor extension to the existing input-displacing abatement method.

While the dataset is based on ENS model data, it may be outdated, compared to the data used in the ENS model framework. Finally, we note that updates to this dataset are not currently publically available.

2.4 Heat sources of households

ENS publishes a technology catalog, which details the costs and heating effects of heating sources for households, e.g., heat pumps, gas and oil boilers and district heating substations. However, this catalog does not detail the potentials for each technology. Further, no information exists on the existing stock of the different heating technologies. This means that it is not possible to directly use the input-displacing abatement method of Berg et al. (2020).

As described in the beginning of section 2, one possibility would be to infer potentials form an expert judgement of baseline technology adoption. However, since there are several technologies that use the same energy input (e.g., several types of heat pumps), it is not possible to infer baseline adoption from the officially available energy use forecasts of the Danish Energy Outlook.

As a result, we do not currently use this technology catalog in GreenREFORM. Instead, marginal properties are handled by the energy demands derived from the standard CES utility function.

2.5 Electric appliances of households

The data households' electric appliances come from ElModelBolig, a yearly survey and forecast conducted by a consultant (Big2Great) for The Danish Energy Agency. The dataset contains information on the stock of different types of appliances, the electricity use of appliances as well as a forecast of appliance electricity use at the appliance level and for Danish households in aggregate. GreenREFORM has obtained the data from the Danish Energy Agency, but the data is not publically available.

The dataset is not a technology catalog in the narrow sense defined above, because it does not include information on savings potentials and costs. However, the dataset does allow for inferring, e.g., at which electricity price it is profitable to replace old, but still functional appliances with new and more energy-efficient ones. This would in essence require a vintage model of a range of electric appliances.

In order to do this, information on depreciation rates as well as appliance prices would need to be added. A vintage model would thus introduce additional assumptions, as well additional model complexity. For these reasons, we opt for a simpler approach, where we use the energy demand forecast as an expert judgement, that we calibrate our model to. We then let the the standard consumer demand function the marginal response to e.g., a change in the electricity price.

This modelling choice implies that nearly no data processing is necessary, since we simply let the data decide the households' non-transport, non-room heating electricity demand.

2.6 Agriculture

Agriculture has a range of technologies available that reduce non-energy emissions related to agricultural production. These technologies are best described as end-of-pipe technologies, i.e., they work to reduce emissions at some cost without affecting the rest of the production function. We currently implement the technologies described in the background material of The Danish Energy Outlook, which details potentials and baseline adoption rates for several technologies. Technology costs are obtained from Dubgaard and Ståhl (2018). More details on the implementation can be found in Beck et al. (2020).

It would be preferable to expand this list of technologies, and update the existing cost estimates. This is a straightforward procedure, given available data. However, such data is currently not available.

2.7 Transport and power-to-x

Households and firms can abate emissions from transportation by using low- or zero-emission vehicles. Similarly, refineries can lower the carbon content of fuels by using new technologies for producing renewable fuels. This includes Power-to-X technologies. Technology catalogues in the transportation model of the GreenREFORM model relates to both vehicles and fuel producing plants.

The model currently uses the underlying data in the Danish Energy Agency's Alternativ Drivmiddelmodel. This data consists of both data for fuel producing plants and vehicles and describes the development in existing and future technologies until 2050. Hence, the data set describes the plants that the refinery industry can invest in and the vehicle technologies that firms and households in general can invest in. It should be noted that the vehicle categories are fully consistent with the inventory of the current vehicle fleets received from Statistics Denmark and used in the model to disaggregate the transportation capital stock. This data also have the advantage of including reference technologies, i.e. baseline existing technologies. Hence, even for existing fossil-based technologies future expected changes in the technology is included in the data. The primary disadvantage of the ADM data is that the model has not been updated since January 2016 and is not expected to be updated again. Furthermore, data for the production of biofuels has not been updated since 2014. Besides the techno-economic data being potentially out-of-date even for existing technologies, it also implies that some technologies are not available in the data even though some technologies are currently being developed and expected to available before 2050. For instance, relatively few alternative technologies are available within trucks and ships. Electricity-based technologies are currently viewed as a potential future technologies within the foreseeable future but are not included in the data. The same holds for fuel-producing technologies. Only two Power-to-X technologies are included in the data (Power-to-Hydrogen and Power-to-Methanol). Finally, the investment costs needed to expand the distribution network of fuels is currently only available for compressed natural gas.

The Danish Energy Agency publish a separate technology catalogue for renewable fuel producing plants. The latest update of this catalogue is July 2020. This data contains the newest estimate of the techno-economic potential for renewable fuel producing technologies. Furthermore, the technology catalogue contains more examples of Power-to-X technologies (e.g. Power-to-JetA1). A disadvantage of this catalogue is that emissions coefficients (for e.g. process emissions) are not included in the data. Thus, additional assumptions would be required to integrate this catalog into the model.

Integration of technology catalogs in the transport module is described in further details in a forthcoming documentation memo on the transport module.

3. Preparation of data: Industrial energy savings

This section describes the data processing necessary in order to integrate data on industrial energy savings in GreenREFORM.

The Danish Energy Agency (ENS) has shared a dataset on industrial energy savings with the GreenREFORM model group. The dataset contains savings potentials and costs at the level of:

- ENS' model sectors
- ENS' model energy services (Electric motors, Light and appliances, Room heat, High temp process heat, Medium temp process heat, Internal transport)
- Energy savings potentials split by whether the energy use is covered by ETS or not

The preparation takes this dataset and computes potentials and costs at the level of:

- GreenREFORM sectors (using ENS sector information)
- GreenREFORM energy purposes and energy inputs (using information on ENS' energy services and ETS/non-ETS and additional data and assumptions)

In the following, we describe how this transformation is carried out.

A mapping between ENS' sectors and the sectors of GreenREFORM can be constructed, since both sector lists map to the 117 national accounts sectors.

We construct a mapping from ENS' energy services to energy purposes and –inputs of GreenREFORM using the assumptions detailed in table 3.1. This mapping show how technologies of ENS' catalog are mapped to GreenREFORM energy purposes and energy inputs. In the cases where multiple ENS purposes are mapped to a single GR purpose, it is necessary to estimate how much of the GR purpose that is covered by each of the ENS purposes.

Table 3.1
Sector and purpose mappings used for industrial energy savings technology catalog

ENS - ETS covered?	ENS energy service	GR energy purpose	Energy inputs
ETS	• Electric motors • Lights and appliances	• ETS	Electricity
ETS	• Internal transport	• ETS	Transport fuels
ETS	• Room Heat • High temp process heat • Medium temp process heat	• ETS	All excluding electricity and transport fuels
Non-ETS	• Electric motors • Lights and appliances	• Process	Electricity
Non-ETS	• High temp process heat	• Special process	All
Non-ETS	• Medium temp process	• Process	All excluding electricity

ENS - ETS covered?	ENS energy service	GR energy purpose	Energy inputs
Non-ETS	• Room Heat	• Room heat	All
Non-ETS	• Internal transport	• Transport	All

Note: Transport fuels are petrol and diesel used for transportation.
Source: Own presentation.

As an example, the sum of ENS services “electric motors” and “lights and appliances” are assumed to match the electricity use of the GreenREFORM energy purpose “Process”. If the potential of a technology that covers the ENS service “electric motors” is 10%, the potential of this technology on electricity use for the GR purpose “process” should be less than 10%, since a share of electricity use for “process” is “lights and appliances”.

We adjust potentials using an additional dataset, namely Viegand Maagøe (2015, (VM2015)). From VM2015 we extract sector-specific shares of e.g. energy used for “electric motors” as a share of energy used for “electric motors” and “lights and appliances”. Additional sector mappings are required, as the VM2015 data is collected on 46 sectors, some which cover multiple national accounts sectors, and some which cover only a part of a single national accounts sector.

The mapping of table 3.1 determines is crucial for determining the absolute potentials (i.e. measured in GJ’s) of the different technologies. It is, however, a relatively crude mapping, and there is no guarantee that the absolute potentials of technologies match between GreenREFORM and the IntERACT model.

Table 3.1 is also an example of our approach to handling energy savings that are measured in terms of general energy demand rather than specific fuels, as described in the beginning ofsection 2. Thus, the final column of table 3.1 makes assumptions as to which energy inputs that each technology can be used on. This approach is subject to the benefits and drawbacks discussed in section 2.

4. References

Andersen, K. S., Wiese, C., Petrovic, S., & McKenna, R. (2020). Exploring the role of households' hurdle rates and demand elasticities in meeting Danish energy-savings target. *Energy Policy*, *146*, 111785. https://doi.org/10.1016/j.enpol.2020.111785

Beck, U. R., Berg, A. K., Christiansen, S., & Jørgensen, C. M. L. (2020). *Agricultural production and emissions in GreenREFORM* [Economic memo]. DREAM.

Beck, U. R., & Kirk, J. S. (2020). *Implementation of input-displacing abatement technologies in GreenREFORM* [Economic memo]. DREAM.

Berg, R., Leisner, J., & Nielsen, A. T. (2020). *Input-Displacing Technologies in GreenREFORM*. University of Copenhagen.

COWI. (2015). *Kortlægning af energisparepotentialer i erhvervslivet*. COWI for Danish Energy Agency.

Danish Energy Agency. (2020). *Denmark's Climate and Energy Outlook 2020*. Danish Energy Agency.

Dubgaard, A., & Ståhl, L. (2018). *Omkostninger ved virkemidler til reduktion af landbrugets drivhusgasemissioner* (IFRO Rapport Nr. 271). Institut for Fødevare- og Ressourceøkonomi, Københavns Universite.

Stephensen, P., Berg, R. K., & Beck, U. (2020). *End-of-pipe emissions abatement technologies in a CGE-model, version 2*. DREAM.

viegand maagøe. (2015). *Kortlægning af Energiforbrug i Virksomheder*.