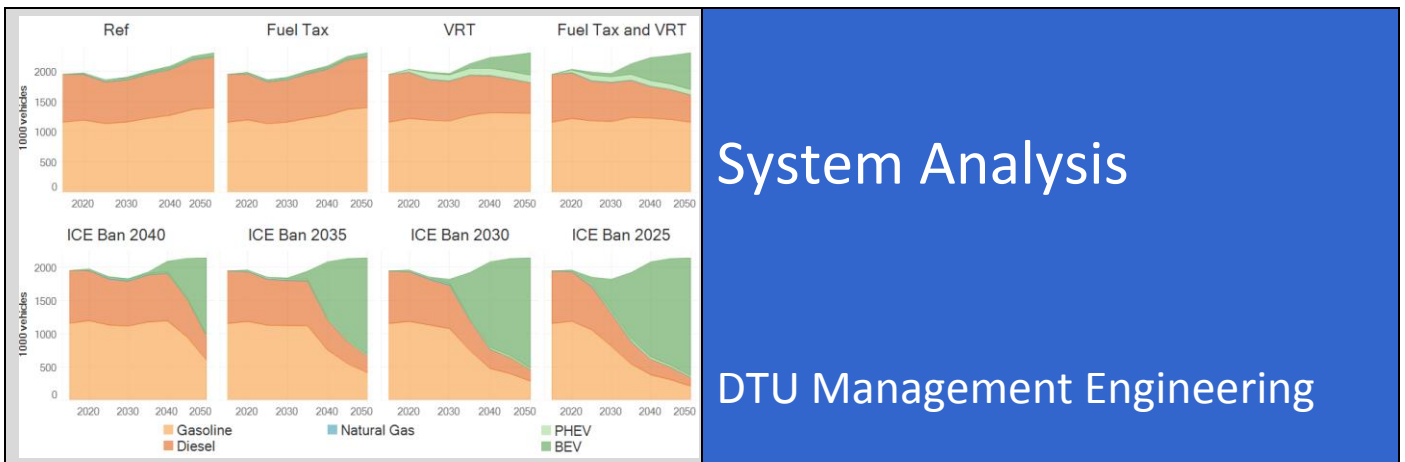# Integrating realistic technology's retirement profiles in TIMES models – The case of the Danish car sector

System Analysis

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Integrating realistic technology's retirement profiles in TIMES models – The case of the Danish car sector

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Abstract Policy analyses conducted with national TIMES models identified that the representation of retirement profile in the car sector is overly optimistic. In traditional TIMES models, the capacity of future installed technologies is constant until the end of the lifetime. However, analyses on cars' retirement profiles found out that the real-life retirement profiles are far from constant. They are characterised by a low decay in the first years after purchase and by a long tail in the distribution, meaning that few cars remain in the car stock for long time. A recent version of the TIMES code (TIMES v4.2.0) has been equipped with a novel attribute that enables to improve the representation of technology's retirement profile. This study utilizes such new attribute within TIMES-DKMS soft-linked to DCSM (the Danish Car Stock Model), aiming at reaching a more detailed and realistic representation of the survival profile of car technologies. The study finds out that an early ban on sales and import of internal combustion engine (ICE) cars is not sufficient to decarbonise the Danish inland transportation sector by 2050, and that scrapping incentives are needed to replace ICE cars with low- and zero-emission vehicles, thus enabling the fulfilment of the Danish environmental targets in 2050.

1 Motivation and background

The necessity to improve the representation of future available technologies' retirement profiles in TIMES models stems from the evidence observed using TIMES-DKMS (the TIMES model of the Danish energy system equipped with endogenous modal shift) [1] and the Irish TIMES (the TIMES model of the Irish energy system) [2] for policy analyses. The use of TIMES-DKMS soft-linked to the Danish Car Stock Model (DCSM) [3] for analyzing a long-term strategy to decarbonize the Danish inland passenger transport sector highlighted that "TIMES-DKMS results do not take into account that even with a ban on internal combustion engine (ICE) vehicles in 2025, there would still be some ICE vehicles circulating in 2050 according to DCSM..." [4]. The use of the Irish TIMES soft-linked with the Irish CarSTOCK model to analyse energy efficiency targets on the car transport sector observed that "The Irish TIMES model uses a constant 15 year lifetime for vehicles, while in the CarSTOCK model lifetimes are based off historic scrappage profiles which are realistically longer than the Irish TIMES assumption. This results in a larger percentage of the car fleet in the CarSTOCK model to be fuelled by fossil fuels in 2050 while the Irish TIMES model has all electric vehicles by this year" [5]. The effect of the simplified representation of car technologies' retirement profile in TIMES models is illustrated in Figure 1, which compares the evolution of the car stock in Denmark between 2015 and 2050 as determined by DCSM (on the left) and by TIMES-DKMS (on the right) [4].
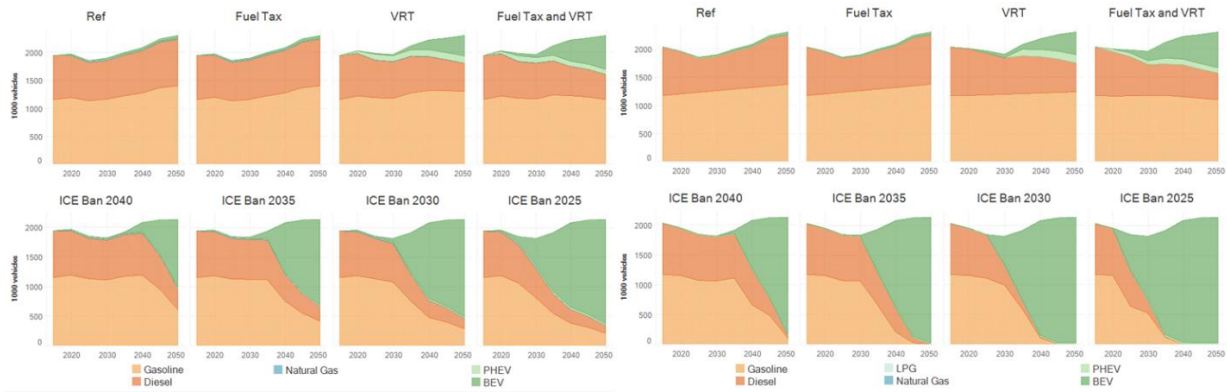
Figure 1: Comparison of the evolution of the car stock in Denmark between 2015 and 2050 according to DCSM (on the left) and according to TIMES-DKMS (on the right)

The comparison of the results of the two models reveals that TIMES models are too optimistic regarding the retirement of the technologies. While TIMES-DKMS determines that a ban on the sales and import of ICE cars in 2025 would entail the complete electrification of the car stock already in 2040, DSCM suggests that in this scenario about 15% of the total car stock would still be constituted by ICE cars. A similar conclusion applies also to the scenarios assuming an ICE ban in 2030, 2035 and 2040: in all these scenarios TIMES-DKMS underestimates the permanence of ICE cars in the stock. The reason for such behavior of TIMES models is attributable to the fact that traditionally the capacity of technologies available from future years is represented by a constant distribution that lasts an amount of years equal to the lifetime specified for the technology (16 for car technologies in the case of TIMES-DKMS). However, this situation is far from reality, as shown in Figure 2, which depicts the retirement profile for cars of different sizes and fuel types in Denmark [3]. The figure reveals that the probability of survival of Danish cars initially is above 100%, meaning that Denmark imports several second-hand cars from other countries. Then, the probability of survival declines smoothly, until scrapping after about 35 years. It is also interesting to observe that diverse car technologies have different retirement profiles, due to the variation in the level of deterioration for each technology.
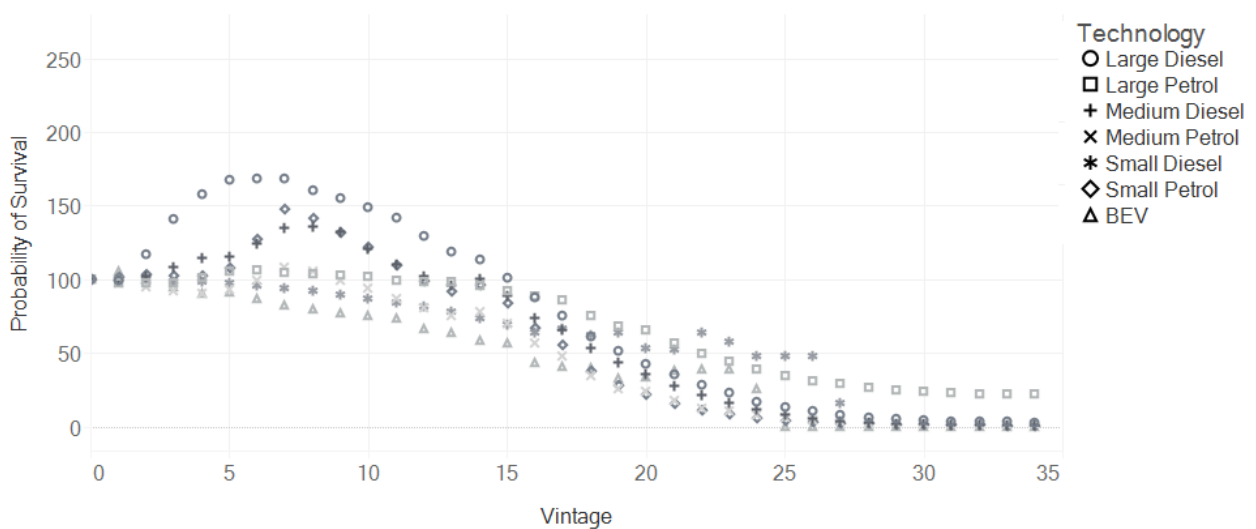

Figure 2: Probability of survive for cars of various fuel types and sizes in Denmark

To overcome the poor representation of technologies' retirement profile in TIMES models, recently a new attribute has been embedded in the TIMES code. In this study, the novel attribute is tested within a multi-method approach that integrates two models, a bottom-up (BU) optimization energy system model and a transport sectoral simulation model. The description of the modeling framework adopted for this study and the description of the new attribute are provided in the next section.

2   Methodology

This study is carried out using the same methodology already adopted in [4] for analysing the effectiveness of alternative policies affecting car choice to decarbonize the inland passenger transport sector. A multi-method approach is used, which integrates TIMES-DKMS (the TIMES energy system model of Denmark equipped with modal shift) with DCSM (a consumer choice model of the private transport sector accompanied by a sectoral simulation model of the private car sector). The remaining of this section first provides an overview of the multi-model approach utilized for this study and then focuses on the new attribute integrated in the TIMES code to enable shaping technologies' retirement profile. A detailed description of the two models soft-linked is provided in [1] [3] [4].

2.1   Modeling framework

The multi-model framework used is obtained soft-linking TIMES-DKMS and DCSM. The policy measures are run in parallel in both models. First, TIMES-DKMS determines the cost-optimal portfolio of technologies to fulfil the exogenous energy-service demands while complying with all the technical, environmental, policy and resource availability constraints. However, the description of the private car sector in TIMES-DKMS is purely techno-economic, and does not account for heterogeneity within the private car market, thus suggesting a solution that may not be technically feasible [6] [7]. Therefore, in a second moment DCSM is used to verify the technical feasibility of the car technologies deployment pattern determined by TIMES-DKMS. If the solution is not feasible, capacity constraints limiting the stock of specific car technologies are added in TIMES-DKMS to comply with the realistic evolution of car technologies determined by DCSM. A new solution is obtained with TIMES-DKMS, which is again verified in DCSM. Data exchange between the two models is iterated until there is convergence between the results (Figure 3).
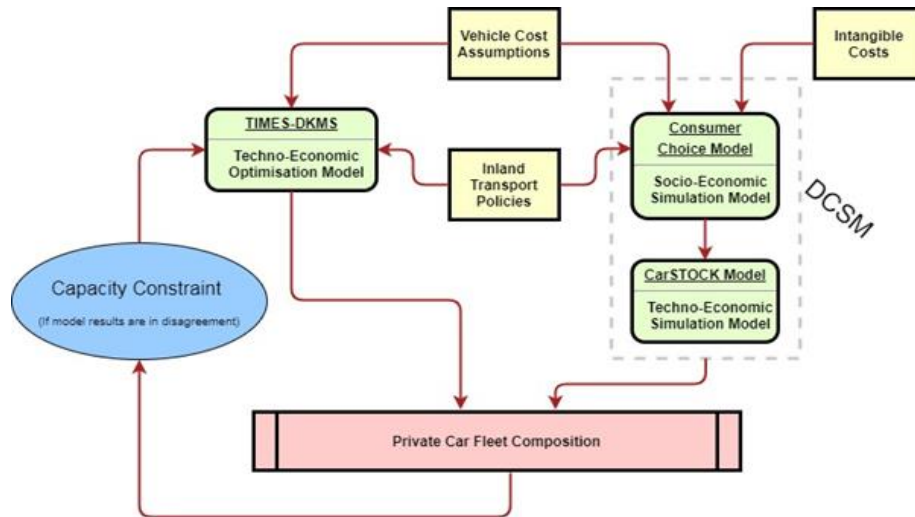
Figure 3: Model integration between TIMES-DKMS and DCSM

2.2 New attribute in TIMES

The latest version of the TIMES code (v4.2) includes a new attribute, *NCAP_CPX*(r,y,p), which allows to shape the available capacity of a process by age. The attribute defines how much of the capacity installed in vintage year v is still available in period t, by using an age-based multiplier in combination with the *NCAP* attribute. A detailed description of the new feature together with some side-effects of its implementation is provided in [8]. The use of *NCAP_CPX* is done in combination with a shape parameter, as visible in Table 1.

Table 1: Shaping the available capacity by age for process TPCGSBL2N (future available gasoline car)

~TFM_INS					
Attribute	**Year**	**Other_Indexes**	**DKE**	**DKW**	**Pset_PN**
SHAPE	1	2	1.00	1.00	
SHAPE	2	2	0.95	0.95	
SHAPE	5	2	0.80	0.80	
SHAPE	10	2	0.70	0.70	
SHAPE	15	2	0.50	0.50	
SHAPE	20	2	0.30	0.30	
NCAP_CPX	2012		2	2	TPCGSBL2N
NCAP_CPX	2050		2	2	TPCGSBL2N
NCAP_CPX	0		1	1	TPCGSBL2N

The example described in Table 1**Error! Reference source not found.** first defines a shape parameter identified with the index 2^1 (specified in the column *Other_Indexes*). The shape parameter with index 2 is equal to 100% when the age of the technology is 1 and then reduces until reaching 30% when the age of the technology is 20 years. After the description of the shape parameter, the capacity shape attribute associated to the technology *TPCGSBL2N* (gasoline car which starts being available from 2012) the shape parameter with index 2 in years 2012 and 2050. Moreover, the interpolation rule number 1 (interpolation between data points only) specified in the last row of Table

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1.   [1] The index 1 is always reserved to the constant SHAPE of 1 [9].

1 specifies that the shape parameter is applied to *TPCGSBL2N* between years 2012 and 2050. The number of shape parameters that can be defined is almost unlimited, while the number of years that can be specified for each shape parameter is limited to 999 [9]. Besides defining the shape parameters and associating it to a process, to correctly use the new feature it is also necessary to ensure that the lifetime of the process to which the capacity shape attribute refers is able to accommodate the entire retirement curve. This can be done either defining the lifetime of the technology from scratch, or overwriting the previous definition through a *TFM-INS* table, as shown in Table 2**Error! Reference source not found.**. In both cases, the attribute "life" is used.

Table 2: Overwriting the lifetime of the technology to accommodate the full retirement curve

~TFM_INS					
Attribute	**Year**	**Other_Indexes**	**DKE**	**DKW**	**Pset_PN**
LIFE	2012		25	25	TPCGSBL2N

3   Results

This study applies the novel capacity shape attribute to the modeling framework described in section 2.1 (TIMES-DKMS soft-linked to DCSM) to improve the representation of the retirement profile of car technologies in Denmark. The implications of the use of such new feature to the decarbonisation of the Danish inland passenger transportation sector are hereby analysed by comparing, for different scenarios, the results obtained with two versions of the modeling framework: one with the original version of TIMES-DKMS (the same model used in [4]) and one with TIMES-DKMS equipped with the capacity shape attribute.

This section first shortly describes the scenario analysed and then presents the comparison of the evolution of the car stock and the greenhouse gas (GHG) emissions determined by the multi-method approach with and without the novel attribute.

3.1   Scenario definition

The scenarios analysed in this study are the same already evaluated in [4]. Table 3 provides a synthetic description of the scenarios, while more details are provided in [4]. All policy scenarios are consistent with Denmark's target of becoming independent from fossil fuels by 2050 [10]. This constraint is set on all the energy sectors represented in TIMES-DKMS, with the exception of inland transport, for which the policies under assessment are the only option to reach the decarbonisation.

Table 3: Description of scenarios for the policy analysis

Scenario	Description
Ref	Reference scenario, only 2020 targets included.
Fuel Tax	The tax paid on electricity used for transport, equal to 245.8 DKK/GJ in 2015, is derogated from 2020 onwards.
VRT	The Vehicle Registration Tax (VRT) is derogated for all electric, hybrid and hydrogen vehicles from 2020 onwards.

Fuel Tax and VRT	Combination of the scenarios Fuel Tax and VRT.
ICE Bans	A ban on the purchase of new ICE cars is introduced from the year 2025, 2030, 2035 or 2040 (i.e. four scenario variants).

3.2 *Evolution of the car stock*

The adoption of the capacity shape attribute to shape the available capacity of a future technology by age manages to realistically depict the real-life retirement profile of car technologies in Denmark. Figure 4 compares the evolution of the car stock in DCSM (left) and in TIMES-DKMS integrating the novel attribute (right). The comparison reveals that the new feature enables TIMES-DKMS to achieve a car substitution pattern very similar to the one determined by DCSM. With respect to Figure 1, TIMES-DKMS equipped with the capacity shape attribute achieves a better description of car technologies' retirement profile. This is clearly visible observing the scenario *ICE Ban 2025*: in this case, differently from the model without the capacity shape attribute, in 2050 there are still some ICE car available despite the early ban on their sales and import.
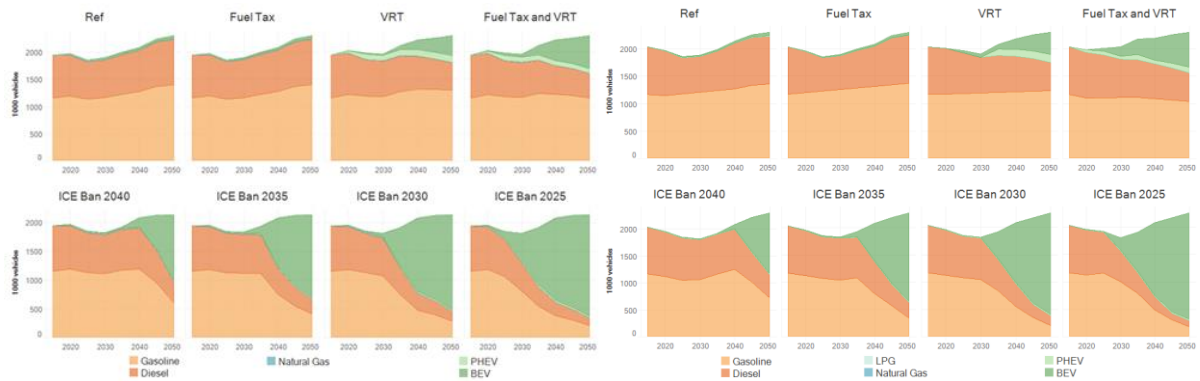

Figure 4: Car stock evolution between 2015 and 2050 according to DSCM (left up and left bottom), TIMES-DKMS (right up) and TIMES-DKMS equipped with the capacity shape attribute (right bottom)

As a consequence of the more realistic cars' retirement profiles and their permanence in the stock for long time, the introduction of the new attribute impacts GHG emissions, too. The comparison of the annual GHG emissions from inland passenger transport sector determined by TIMES-DKMS with and without the capacity shape attribute (Figure 5) reveals two important facts. On one hand, no one of the policies analysed is able to completely decarbonize the inland passenger transport sector by 2050: the consumption of oil products by ICE cars entails some GHG emissions even in 2050. On the other hand, the GHG reduction pace determined by TIMES-DKMS when the capacity shape attribute is adopted is slower than the one without it.
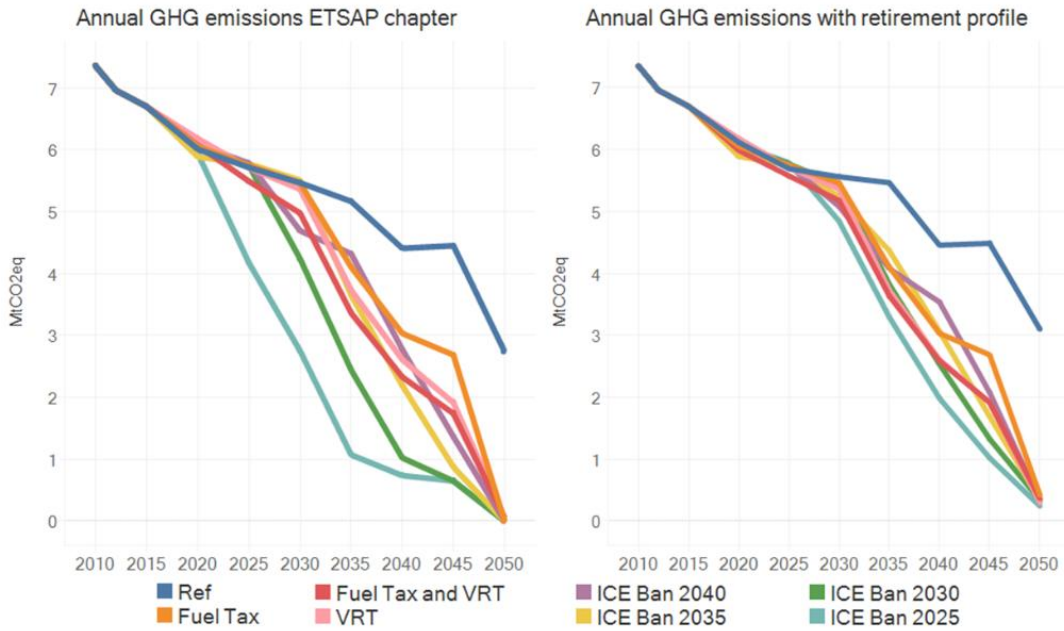
Figure 5: Annual GHG emissions from inland passenger transport sector in TIMES-DKMS without the new attribute (left) and with the new attribute (right)

The slower GHG reduction pace entails that cumulative GHG emissions along the modeling time horizon are higher than initially determined in [4], as demonstrated in Figure 6. In particular, the cumulative GHG emissions in 2050 determined in this study for the scenarios *ICE ban 2040, ICE ban 2035, ICE ban* 2035 and *ICE ban 2025* are respectively 5%, 7%, 16% and 30% higher than in [4]. This finding is very important in the light of the Paris Agreement, which aims at limiting the amount of cumulative GHG emissions to a level consistent with a global temperature rise of 1.5°C above pre-industrial levels [11].
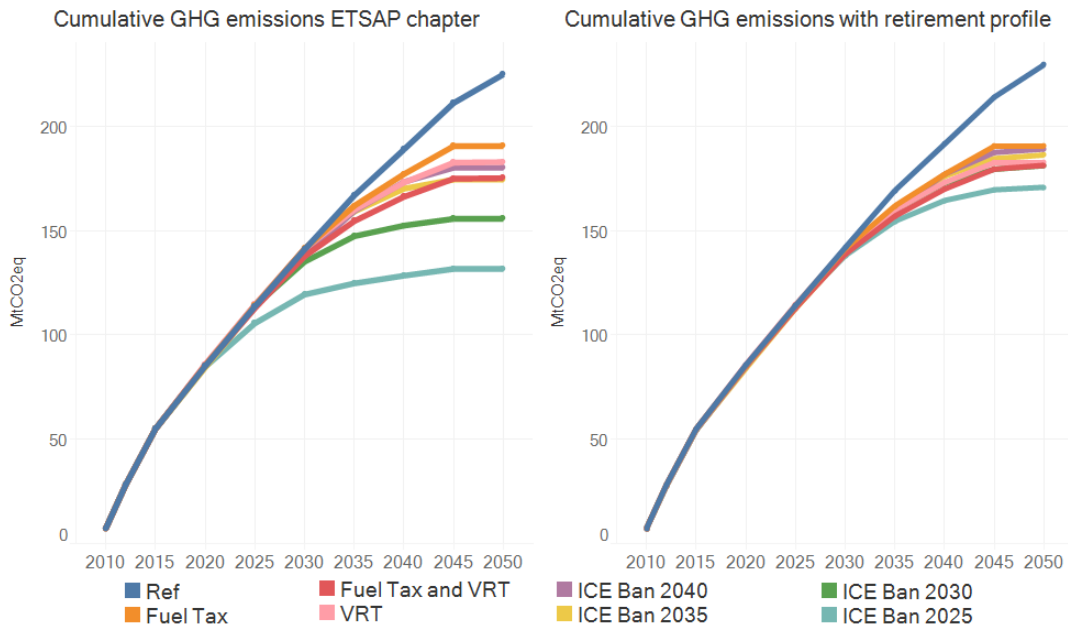

Figure 6: Cumulative GHG emissions from inland passenger transport sector in TIMES-DKMS without the new attribute (left) and with the new attribute (right)

4   Discussion and conclusion

The new the capacity shape attribute embedded in TIMES v4.2 enables to define more realistically the capacity of a future available technology by vintage, thus improving the representation of technologies' retirement profile. The novel attribute has been tested on TIMES-DKMS, applying it to the future available car technologies defined in the model. The incorporation of the attribute is simple and does not require particular changes to the structure of the model, while it allows to achieve a better description of the decarbonisation dynamics. In particular, this case study has highlighted that the long permanence of ICE cars in the stock implies that the total decarbonisation of the car sector requires additional efforts than initially evaluated. Neither an early ban on the sale and import of ICE cars is sufficient to achieve GHG free car sector in 2050.This result suggests that Denmark's compliance with its decarbonisation targets would require to introduce, besides policies encouraging the adoption of low- and zero-emission cars, incentives to scrap old ICE cars before the natural course.

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