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Evaluating our future

The crucial role of discount rates in European Commission energy system modelling

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19 October 2015

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Introductory remarks and acknowledgements

This report was commissioned and published by eceee with financial support from Energifonden, the European Climate Foundation and Eurima, the European Insulation Manufacturers Association.

Dr Andreas H. Hermelink and David de Jager from Ecofys are the authors. Their work has been guided by a project steering group consisting of Randall Bowie from the board of eceee, Erica Hope from the European Climate Foundation, and Nils Borg, eceee's Executive Director.

During the process, a workshop on discount rates was arranged in Brussels 10 July 2015. eceee and the authors wish to thank all those who participated in the workshop and those who contributed with important and insightful review comments. Without the involvement of so many engaged people, this report would not have been possible.

Disclaimer

eceee has initiated this work and the report reflects the immense importance that eceee attributes to the role of discount rates in energy and climate modelling. However, the views expressed herein are those of the authors and do not necessarily reflect those of eceee or its members, or those of the report's funders.

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One of eceee's principle events is the five-day Summer Study held in June every odd year, which attracts more than 450 participants from governments, industry, research institutes and citizen organisations. Since 2012, eceee also arranges a biennial event devoted to industrial energy efficiency.

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Date: 19 October 2015

Project number: BUIDE16021

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The views expressed in this report are solely the views of the authors. They are based on extensive literature research and discussions during a workshop held in Brussels on 10 July 2015.

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Executive Summary

The International Energy Agency (IEA) has dubbed energy efficiency the "first fuel". In 2011 the achieved savings of 11 IEA countries through energy efficiency since the 1970s equalled the *total* fuel consumption of the whole EU. Energy efficiency by far exceeded decreases of fuel consumption due to the economic crisis in 2008. However, IEA also concludes that world-wide only one third of the economic potential for energy efficiency measures will be exploited under current policies.

Yet, when the European Commission presented its proposal and accompanying impact assessment for a 2030 energy efficiency and greenhouse gas (GHG) reduction target in the summer of 2014, the importance of energy efficiency did not seem to be sufficiently well addressed considering the available cost-effective savings potential. Inappropriately high discount rates being used as inputs for the underlying PRIMES energy system scenarios were identified as a major reason.[1] If the assumed discount rates had been lower, analysts claimed, the Commission could have motivated a much more ambitious proposal, especially for energy efficiency. Why is that? Energy efficiency measures (e.g. in buildings) typically have relatively high upfront costs, which need to be recovered by savings over longer periods. Discount rates are thus used to attribute a value to future cash flows. *The higher the discount rate, the lower the value we assign to future savings in today's decisions. Consequently, high discount rates make energy efficiency measures and supporting policies look less attractive.*

The topic of discount rates deserves special focus and priority since several Impact Assessments will be carried out in the coming months by the European Commission in connection with the review and possible revision of the Energy Performance of Buildings Directive (EPBD), the Renewable Energy Directive (RED), and the Energy Efficiency Directive (EED).

In order to systematically shed light on the use of discount rates in EU Impact Assessments, in this report we examine the discount rate issue in four steps:

1. It briefly describes major aspects of the modelling currently used in EU Impact Assessments, focusing on how discount rates are applied;
2. It explains and illustrates why discount rates used in modelling matter so much for deriving meaningful scenarios about Europe's future energy system, its costs and adequate policies;
3. The report further examines what - compared to current practice in EU energy and climate policy Impact Assessments – various sources reveal about the adequate use and height of discount rates: EC documents and guidelines, common practice in different EU Member States, Member States cost-optimality calculations for verifying their minimum energy performance requirements for buildings as well as further literature on discount rates.
4. Finally, the findings are summarised and recommendations derived for the appropriate use of discount rates in EC Impact Assessment. It also suggests next steps to be taken.

[1] PRIMES is one of the major models used by the European Commission for assessing the economic impact of different EU energy policy options.

Understanding the two steps in PRIMES energy modelling

In order to understand the report's conclusions, it is helpful to understand why the inputs used in the two major steps of the underlying PRIMES modelling matter so much

- *In the first step*, technology choice is modelled, mimicking an agent who is taking decisions based on the net present value of that technology's life-cycle cost. As explained above, high discount rates make energy efficiency measures look less attractive. Therefore it is important that PRIMES assigns a "subjective" discount rate when predicting technology investment decisions. This (high) subjective discount rate is not only to reflect actual cost of capital but also various kinds of *perceived* barriers like needed change of habits, lack of information etc. It is often called "implicit discount rate" since it is derived from observed investment decisions rather than from statements of rational economic agents.
- *In the second step*, a discount rate is applied in order to evaluate the annual total cost of the energy system - resulting from step 1 choices - from a societal perspective. This again is a net present value calculation, i.e. the energy system featuring the lowest NPV is deemed to be the best choice from a societal perspective.

Main findings and conclusions

1. The choice of discount rates has a significant impact on the evaluation of policy options.

This first finding is to emphasize the importance of applying very well-considered discount rates both in steps 1 and 2 of the modelling as explained before. Discount rates have a striking impact on the evaluation of different energy and climate policy options. The higher the discount rate, the lower the value we assign to future savings in today's decisions and the less attractive high-energy-efficiency investments and supporting policies get.

2. The use of discount rates for modelling of individual investment decisions and for the evaluation of energy system costs from a societal perspective must be kept apart. This is currently not the case.

Recent EU Impact Assessments of energy and climate policy options have been conducted with insufficient separation of two completely different aspects, where discount rates play a major role:

- The modelling of individual decisions about technology choices.
- The evaluation of energy system costs from a social perspective.

This is our major concern with recent Commission practice. We could not find any plausible explanation in the supporting documents as to why the Commission uses the *same* high discount rates for predicting individual decision making as for the calculation of the energy system costs from a societal perspective as an input to PRIMES modelling.

3. Member States use much lower discount rates than recent EC Impact Assessments.

Neither economic theory nor actual Member States' practice provide good reasons for the major differences between discount rates that we observe to be used in EU Impact Assessments and Member States individual impact assessments. In fact some Member States explicitly follow the clear advice from earlier EU Impact Assessment Guidelines to use a discount rate of 4%.

4. Discount rates used in EC Impact Assessments for determining the annual total energy system costs should be revised.

Preferably an EU wide social discount rate should be calculated based on existing theory. If no consensus can be found about going that way, an average EU Weighted Average Capital Cost (WACC) could be calculated. Either way, we assume the result will be in the range of 3% to 6%, as compared to the 17.5% used in the Impact Assessment for the 2030 energy and climate policy framework.

5. The translation of barriers and policy measures into "subjective" discount rates needs to be transparent.

In PRIMES, the "subjective discount rate" is the major parameter mimicking individual decision making about technology choices. However, there is no common understanding on how to translate individual behaviour and time/risk preferences into subjective discount rates. This should be the reason for giving a fully transparent explanation for how the discount rates used in PRIMES modelling are set and how they adapt as a consequence of targeted energy policies.

6. The role of Impact Assessments is to support and not to replace policy making. PRIMES inputs, logic and outputs should be fully transparent. Outputs should always be tested against other modelling tools.

Modelling must be useful to support policy makers in their decisions; *a pre-condition is that policy makers can understand what is going on in the modelling.* Even for scientists PRIMES documentation does not allow full verification. Therefore we have the following recommendations:

- Information about inputs, logic and outputs should always be provided in every Impact Assessment in a well-structured transparent way, which above all enables policy makers to consciously use the modelling as a decision support tool.
- EC Impact Assessment, and specifically PRIMES modelling, should consistently apply sensitivity analysis, to foster the understanding for different parameters' impact on the preferable energy system.
- PRIMES scenarios should always be verified with results from other modelling tools. Reasons for differences must be understood and if need be inputs and/or algorithms in one or the other model adapted.
- Evolution of PRIMES is inevitable due to the rapid changes in the energy system we are witnessing today. It should have priority over its ability to reproduce former results. Relative standstill in PRIMES' development would undermine the value of PRIMES' modelling results. This view is in line with Pfenninger et al who state that "we always need to keep aware whether current methods are appropriate for 21st century problems". Under any circumstances we need "to avoid the trap of modelling what is easily quantifiable rather than what really matters."

1 Objective of this study

The IEA's Energy Efficiency Market Report 2014 confirmed energy efficiency's place as the "first fuel", meaning that the avoided energy use was larger than the single supply of oil, gas or electricity. In 2011 the achieved savings since the 1970s of 11 IEA countries[2] equalled the *total* fuel consumption of the whole European Union. In-depth IEA analysis reveals that energy efficiency by far exceeded structural decreases of fuel consumption following the economic crisis in 2008 and in many cases overcompensated increases caused by higher economic activity between 2001 and 2011 [OECD and IEA, 2014a]. According to IEA's report "Capturing the Multiple Benefits of Energy Efficiency" "macroeconomists have stated that energy efficiency is the surest energy supply that exists." Still the same report also reveals that world-wide only one third of the economic potential for energy efficiency measures will be exploited under current policies [OECD and IEA, 2014b]. This impressively underlines the importance of both energy efficiency and adequate energy (efficiency) policies for economic growth and achieving energy and climate policy targets.

Neither the importance of energy efficiency nor adequate corresponding policies seemed to be sufficiently well addressed in the eyes of well-known analysts when the European Commission presented its proposal and accompanying impact assessment for a 2030 energy efficiency and greenhouse gas (GHG) reduction target in the summer of 2014 [e.g. [Deutsch et al., 2014], [Held et al., 2014]]. Inappropriately high discount rates being used as inputs for the underlying PRIMES energy and climate scenario models[3] were identified as a major reason [Pollitt et al., 2015][Steinbach et al., 2015]. If the assumed discount rates had been lower, these analysts claimed, the Commission could have motivated a much more ambitious proposal specifically for energy efficiency [Dupuy, 2015]. Why is that? Energy efficiency measures (e.g. in buildings) have typically higher upfront costs which have to be recovered by savings over typically longer (technical) periods. Discount rates are used to attribute a weight to future cash flows. The higher the discount rate the lower the weight of future savings in today's decisions – and the less attractive energy efficiency measures and supporting policies. Lower discount rates thus make room for stronger energy efficiency policies. But why are the applied discount rates in the EC's Impact Assessment so high, and do they need to be?

The topic of discount rates deserves special focus and priority since several Impact Assessments will be carried out in the coming period by the European Commission, i.e. on:

- the Energy Performance of Buildings Directive (EPBD),
- the Renewable Energy Directive (RED), and
- the Energy Efficiency Directive (EED).

The results of these Impact Assessments, which again will apply discount rates, will substantially influence the roles and ambition levels of energy efficiency, GHG emission reductions and the use of

[2] Australia, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Sweden, the United Kingdom and the United States
[3] PRIMES is a modelling tool used to generate the official EU energy and GHG projections, trying to reflect the impact of different potential policy contexts and thus providing major support for policy makers as to future energy and climate policies in the EU (Smit et al. 2014).

renewable energy. Moreover a new reference scenario for the "business as usual" primary energy consumption in the EU till 2030 is planned for the end of 2015/beginning of 2016.

In order to systematically shed light on the use of discount rates in EU Impact Assessments, we invite you to follow us through the discussion, in four steps:

- In chapter 2 we briefly describe major aspects of the modelling currently used in EU Impact Assessments and highlight major concerns as to the appropriateness of how energy efficiency investments and specifically discount rates are applied.
- In chapter 3 we explain why discount rates used in modelling matter so much, first by providing general insight, then illustrating it with two examples.
- In chapter 4 we provide evidence from studying different sources: what do different EC documents tell us about appropriate discount rates? What can we learn from publications about the underlying PRIMES modelling and from further literature? What is common practice in different EU Member States and what discount rates did they apply in their cost-optimality calculations for verifying their minimum energy performance requirements for buildings?
- In chapter 5 we conclude our findings and derive recommendations for the appropriate use of discount rates in EC Impact Assessment and next steps to be taken.

2 What happens in EC Impact Assessments?

2.1 Description of the approach taken in EC Impact Assessments

One of the major models used by the European Commission for assessing the economic impact of different EU energy policy options is PRIMES. PRIMES has been developed since the 1990s at the National Technical University Athens (NTUA). According to a classification of models done by [Després et al., 2015] PRIMES is a partial equilibrium, simulation model. This means that PRIMES focuses on the energy system, rather than the whole economy: "Technology learning and economies of scale are fully included and are generally endogenous depending on market development. PRIMES is designed to provide long term energy system projections and system restructuring up to 2050, both in demand and supply sides. … The linked model system PRIMES, GEM-E3 and IIASA's GAINS (for non-CO_2 gases and air quality) performs energy-economy-environment policy analysis in a closed-loop" [E3mlab, 2015].

As such PRIMES provides detailed projections of energy demand and supply, including underlying investments on the supply and demand side of energy and emissions.[4] This is done for each European country taking into consideration cross-border energy flows. Energy prices generally result from balancing demand and supply simultaneously in several markets [E3Mlab and ICCS, 2013] and thus are created endogenously[5], i.e. within the model rather than being an exogenous variable. Although incorporating a comparatively precise power system description, model runs are based on annual electricity demand, with restricted capabilities to reflect storage capacities and spatial resolution of demand and supply. Different policy options are modelled in scenarios which are compared to a PRIMES reference scenario [Després et al., 2015]. Such reference scenario includes all the adopted energy efficiency policies both at national and EU level up to the point when the reference scenario is set up. Recent reference scenarios were built in 2007 and 2013 for the purpose of energy system projections till 2020 and 2030 respectively. Building a new reference scenario is scheduled for the end of 2015/the beginning of 2016. The well-known 20% energy efficiency target for 2020 was defined in comparison to what the 2007 reference scenario projected for 2020.

Impact Assessments supported by PRIMES modelling seek to *find the policy mix that minimises annual total energy system cost*. This means that the policy mix leading to the lowest annual total energy system cost is usually evaluated best.

Total energy system costs are derived as follows [E3Mlab and ICCS, 2013] and [European Commission (EC), 2014b]:

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[4] Nevertheless the model is e.g. not doing a bottom-up calculation by residential building type and vintage but rather aggregated by five different space heating patterns (central boiler, electric, direct gas, district heating, partially heated dwellings).

[5] Still e.g. world market prices for oil are fed in exogenously.

- PRIMES reports energy system costs from the perspective of energy suppliers and final energy consumers, namely power sector, tertiary and industry sector, public transport, trucks, private cars and private households.
- Energy system costs comprise annual capital costs and (annual) energy purchases.
- The actual energy system and the total annual energy system cost follow from two steps:
    - Step 1: Decisions about which technologies to select within a restricted budget.
    - Step 2: Accounting of actual total annual energy system costs related to the investments in and running costs of the previously selected technologies.

- **Step 1-decisions about which technology to choose** in PRIMES are taken by the final consumer; actually PRIMES provides a list of technology options from which to choose. Final consumers in PRIMES are simulated as one "stylised agent" per sector (cf. Table 1). From all documents we analysed, technology decisions seem to be mainly driven by "perceived" investment cost and the "subjective" discount rate of each stylised agent. In our discussions about how technologies are selected in PRIMES it turned out that also payback times and maybe even other factors might potentially play a very significant role in technology decisions. Yet the exact mechanism remained unclear as no further details are provided in the PRIMES model descriptions.[6] The model developers "regard it a distinctive feature of PRIMES that a combination of behavioural modelling following a micro-economic foundation with engineering and system aspects, covering all sectors and markets at a fairly high level of detail" is applied in PRIMES [E3mlab, 2015].
    - Depending on the uncertainty the agent attributes to certain technologies "that are assumed not to be mature yet in early stages of projection" a risk premium is added to the actual investment cost[7] resulting in "perceived" investment cost.
    - As to "subjective" discount rates used in PRIMES some more explanation is needed. According to [E3mlab, 2015] and [European Commission (EC), 2014d] PRIMES aims at mimicking true decision making of private actors about investment choices. As private actors perceive a multitude of technical, administrative and institutional risks, lack of information and specifically limited access to funding, they associate very high opportunity costs of energy savings and of drawing related funding[8]. From these perceived opportunity costs or from reported expected payback times literature derives very high subjective discount rates (also called "shadow interest rates") for private investors when modelling how they do decisions about investments in energy efficiency.

      For power generation PRIMES assumes weighted average cost of capital (WACC), whereas different subjective discount rates are used for the other sectors [European Commission (EC), 2014c], see Table 1.

[6] This is also the case for how supplements to investment costs are determined in order to arrive at "perceived" technology cost.
[7] The PRIMES model description does not give the details of how exactly "perceived" investment cost are determined. Anyway it is clear that with rising uncertainty there is an increasing supplement to the real investment cost.
[8] Usually opportunity cost is the "not achieved" benefit of an alternative B that cannot be realized due to choosing alternative A. Here it is not used for a real alternative but for a calculated fictitious alternative that is derived from observed behaviour.

- As to **Step 2, accounting of annual total energy system cost**, the PRIMES description explains as follows: "When calculating total costs by year, investment expenditures are annualised to show annual costs from an end-user perspective (from an *opportunity* cost perspective)." The transformation in annual payments allows adding annuities for capital with variable and fixed annual costs in order to report on total costs by sector and overall. Concretely [sector specific] *private* (subjective) discount rates are used for transforming capital costs into annuities.

In a nutshell, in recent Impact Assessments in principle **the same set of discount rates *for both decisions* about which technologies to select *and for accounting* of the annual total energy system cost was used to run PRIMES,** the system cost being the major criterion for how advantageous a certain policy-technology-scenario is. **In the following chapters we'll show that this is the most critical assumption in recent modelling for Impact Assessments.** Table 1 summarises the recently applied subjective discount rates.

Table 1. Discount rates in the PRIMES model [Energy-Economy-Environment Modelling Laboratory - E3mlab, 2014]

Economic agent category	Discount rate	Adjusted discount rate due to the implementation of the Energy Efficiency Directive	
	Default	2015	2020-2050
Power generation	9%	9%	9%
Industry sector	12%	12%	12%
Tertiary sector	12%	11%	10%
Public transport	8%	8%	8%
Trucks/inland navigation	12%	12%	12%
Private cars	17.5%	17.5%	17.5%
Households	17.5%	14.75%	12%

Table 1 also highlights two further aspects: First, different subjective discount rates are applied for different sectors (or categories of economic agents representing these sectors). Second, in some cases, e.g. in the case of households, the implementation of the Energy Efficiency Directive leads to decreasing discount rates over time. According to the PRIMES model description e.g. the household discount rate of 17.5% for business as usual conditions is derived from extensive literature research. In chapter 3.1 we'll show that the consequent lowering of discount rates in decision making and accounting favours energy efficient technologies. This fact is reflected in the discount rates used as an input for PRIMES modelling to a certain extent by assuming that energy efficiency policies, depending on their menu and intensity (which e.g. leads to a certain reduction of above mentioned perceived risks or easier access to funds) progressively decrease subjective discount rates towards market interest rates, as can be seen in Table 1.

In order to model the impact of energy policies PRIMES applies several "model specific instruments [which] affect the context and conditions under which … stylised agents per sector … make their decisions on energy consumption:" …

- Parameters mirroring better technology performance or the effects of building codes.
- Factors that affect the perception of net energy cost … which can be influenced by energy efficiency policies.
- Reduced discount rates for certain sectors [European Commission (EC), 2014a] and [E3mlab, 2015].

Yet there is no description about the (functional) relation between these and other types of policy instruments and corresponding decreases of discount rates in PRIMES modelling.[9]

Note: so far in PRIMES modelling energy efficiency policies *only* seem to reduce subjective discount rates used for *decision making* about technologies but they do **not** reduce subjective discount rates used for *accounting* of the annual total energy system costs; for the latter purpose the "default" rates (see Table 1) are kept constant. Although this fosters that more investment decisions are taken in favour of higher efficiency technologies, the net effect of this imbalance in the approach may be an even higher annual total energy system cost, thus creating a systematic disadvantage for higher efficiency technologies.[10] This will be explained in chapter 3.1. Yet the European Commission seems to be aware of this crucial issue, as in the July 2014 energy efficiency Impact Assessment it says: "So far, *reduced discount rates* in the context of economic decision making of agents, following from energy efficiency policies, *have not been applied in the same way to calculate the capital cost and direct energy efficiency investment component of energy system costs*. With energy efficiency policies increasingly changing energy markets by addressing market failures and imperfections*, it appears appropriate to revisit this issue in future analyses*." [European Commission (EC), 2014c, p. 76]

In order to finalise the description of how discount rates are used in PRIMES according to the available information, in PRIMES modelling also a "social discount rate" of 0% is used for comparisons across scenarios. Actually this means that *by default* no "step 3" discounting is applied when comparing total energy system costs of different scenarios. Of course it is possible to change this rate for the purpose of sensitivity analyses.

[9] Further model features are described which allow for simulating the effects of energy efficiency and energy efficiency policy, such as "efficiency values", enabling conditions etc. which mainly lead to getting "perceived costs" by final consumers closer to engineering estimates for energy efficiency investments. A strong rebound effect (increase of floor area) is considered for residential energy efficiency retrofit, especially in Eastern Europe. Furthermore the concept of "disutility cost" is applied when e.g. higher energy cost force consumers to invest in energy efficiency measures. In case the *perceived* net benefit of this investment is negative (applying subjective discount rates) it is assumed that energy consumers will curtail energy services – the hypothetical cost to compensate for this loss of utility is called "disutility cost" and added to the energy system cost. (Energy-Economy-Environment Modelling Laboratory - E3mlab, 2015) recognizes that this might be a misconception for long-term modelling as utility functions may change in the long run and even new utilities may develop. Anyway the model developers state that "ancillary" benefits like increased value of real estate (which have been found to generate significant economic benefits in above mentioned IEA study on "multiple" benefits) "are not accounted for in PRIMES and so disutility cost may be over-estimated in some cases." This means that future inclusion of "multiple benefits" will probably act as (strong) counterweight to disutility cost.

[10] This is because now *more* high efficiency technologies are chosen than before and consequently are part of the energy system; as they have higher upfront investment cost, their annual *capital* cost (being part of the total annual energy system cost) increase as well due to the unchanged high discount rate for calculating annual capital cost – which may overcompensate the increased savings and eventually leads to even higher total annual energy system cost (annual capital cost + annual energy cost).

2.2 Issues around the current modelling approach with regard to energy efficiency

The previous chapter revealed the following issues with regard to the handling of energy efficiency in recent Commission Impact Assessment, specifically with regard to how discount rates are applied:

- Basically, only one model, namely PRIMES, is taken for modelling, without sufficient sensitivity analysis of major parameters including discount rates.
- The way discount rates are used in both their major applications in PRIMES – decision making and accounting of energy system cost – are rather disadvantageous for the evaluation of energy efficiency measures with relative high upfront cost:
  - High subjective discount rates are used to model *decision making* about technologies
  - High subjective discount rates are used to *account annual total energy system cost*.
  - Energy efficiency policies are translated to decreasing discount rates for the modelling of decision making, while discount rates used for accounting annual total energy system cost remain unchanged. This asymmetry introduces another disadvantage into the evaluation of energy efficiency investments with higher upfront cost.
  - There does not seem to be a difference of applied discount rates between different types of energy efficiency technologies; discount rates only differ between different sectors (or the stylised agents representing these sectors respectively).
- Furthermore, some assumptions are not substantiated or explained:
  - The concrete interrelation between policy measures and their impact on discount rates remains unexplained.
  - The question whether discount rates are appropriate at all for covering real impacts on real decision making behaviour of real agents in today' s and future complex energy systems is not discussed in the EC's impact assessment documents.
- Perceived investment cost reflecting different kinds of investors' risks or risk perception rather than real investment cost is applied. On top the concept of "disutility cost" related to energy efficiency investments without accounting for ancillary benefits seems to put another burden on energy efficiency investments. This may be a crucial issue as well and thus deserves further investigation in future studies. It remains unclear to what extent factors leading to high subjective discount rates are double counted by applying perceived investment cost and disutility cost at the same time.
- Finally it needs to be discussed whether the perspective of a private investor taken in recent Impact Assessments not only for decision making about technologies but also for accounting energy system cost is appropriate for informing decisions about future EU energy policy.

Most of these aspects will be looked at in more detail in the following chapters. We would like to stress that this discussion is not aiming at questioning the appropriateness of PRIMES but rather about the *assumptions* taken for simulations supporting the impact assessment of policy options.

3 Why do discount rates matter?

This chapter gives an introduction to, and more background on the importance of discount rates in Impact Assessments.

3.1 The significance of discount rates in financial calculations

The higher the discount rate the less attractive investment in high-energy-efficiency gets.

Discount rates are used to attribute a weight to future cash flows. For this purpose discount rates are transformed into discount factors [Hepburn, 2007].[11] Assuming a cash flow 20 years from now, for a 1% discount rate the discount factor equals 0.82, while for a 10% discount rate the discount factor equals 0.149.[12] Let that future cash flow be € 1000, then today's relevance would be € 820 or € 149 respectively. Vice versa in order to have the same relevance of € 1000 today, a payment 20 years from now needs to be € 1,220 for a 1% discount rate and € 6,727 for a 10% discount rate. Obviously discounting is important in financial assessments of different investment alternatives having different upfront cost and subsequent cash flows (costs and benefits) at different future moments in time [Renda et al., 2013]. The results of such calculations are used to make alternatives financially comparable and support the decision about which alternative to take.

When talking about investments affecting the energy use in this chapter, we will refer to two simplified cases. They are based on the general (simplified) notion, that technologies using less energy and thus having lower running costs will have higher upfront investment cost. Therefore the usual comparison is[13]:

- Alternative 1 (high efficiency): higher upfront investment, lower energy use and annual energy cost.
- Alternative 2 (low efficiency): lower upfront cost, higher energy use and annual energy cost.

As either (private) equity (which could be invested in profitable alternatives with similar risk) or a loan or a mixture will be used to finance the investment and subsequent payments for energy, the investor will expect a certain rate of return in order to make the investment financially viable. This rate of return is the discount rate. In order to make different alternatives comparable, typically one of the following approaches – global cost (net present value) or annuities - is followed:

a) **Global cost.** This is the financial parameter taken for *decisions* about which technology to choose (e.g. high efficiency vs. low efficiency) in recent Impact Assessments. Here the

[11] As such [Hepburn, 2007] clarifies that the discount rate is the speed at which the discount factor declines from one to zero from now to the future.

[12] Discount Rate DR; Discount Factor: DF; Years from now: T; $DF = 1/(1+DR)^T$; $1/(1+0.01)^{20} = 0.82$; $1/(1+0.10)^{20} = 0.149$

[13] The example is intentionally simplified in order to focus on the impact of discount rates.

discount rate is used to determine the current value of future payments (for energy), i.e. future payments are discounted back to today (the "present") and added to the upfront investment cost. This is called the "net present value", or according to EN15459 the "Global Cost". As the discount factor for future payments (or savings) increases exponentially with the number of years from today, the present value of a future payment decreases a) with its distance from today and b) with increasing discount rates, i.e. the further a payment lies in the future and the higher the discount rate the smaller that future payment's influence on today's investment decision. The advantage of future energy cost savings increasingly melts away with increasing discount rates. Therefore investments in high efficiency get less attractive compared to low efficiency investments, the longer their lifetime and the higher the discount rate used [Hermelink, 2009]. Global cost as decision criterion are also used in cost-optimality calculations for determining the minimum buildings energy performance requirements in Member States. Annex III of this report (chapter 7.2) illustrates for two different energy efficiency investments how high discount rates, like the 17.5% used in recent European Commission impact assessments, can change the preference from a high efficiency alternative to a low efficiency alternative. [14]

b) **Annuities:** This is how annual total energy system cost in recent impact assessments have been calculated. See Annex II of this report (chapter 7.1) for an illustration. The upfront investment is transformed (taking into account lifetime and discount rate) into equal annual instalments ("annuities") over the project's lifetime. When discounting these annuities back to the project start, applying the same discount rate, this results in the so called *present value* of all annuities. It equals the initial investment. The higher the discount rate, the higher the annuities. This also means that the *absolute difference* of annuities of two alternatives having different upfront investments *increases* with increasing discount rates. The total annual cost of an alternative is the sum of annuities plus annual energy costs. The advantage of lower annual energy cost of high efficiency technologies requiring higher upfront investment is increasingly eaten up by increasing discount rates. In any case from a financial point of view the high efficiency alternative loses attractiveness with increasing discount rates. It easily may happen that an energy efficiency alternative may have lower total annual cost compared to a low energy efficiency alternative at a low discount rate but this may reverse at a high discount rate, making the low efficiency alternative more attractive.

When correctly applied both calculation approaches a) and b) lead to the same statement about the financial comparison between alternatives if the annual costs and benefits are constant values, as from a mathematical point of view they are equivalent. If annual costs/benefits differ over time, the global cost method should be applied. In a nutshell assumptions about discount rates, upfront

[14] Positive (i.e. >0) global cost (or net present values (NPV) respectively) are usually the result of calculating the difference between two alternatives, e.g. alternative 1: investing in wall insulation resulting in lower energy bills and alternative 2: no investment in energy efficiency, but continuation of paying higher energy bills. Both alternatives for themselves only produce costs; but when calculating the difference, the investment in insulation produces a negative cash-flow today while afterwards producing energy savings, which are positive cash-flows. When the present value of the sum of positive cash flows (energy savings) is bigger than the initial investment, then NPV > 0. This is the well-known criterion for profitable investments.

investment costs and future energy cost decide about which alternative to take. Two examples will illustrate this rather fundamental insight.

3.2 The electric doorbell example

The impact of applying different heights of discount rates in an impact assessment of policy measures can be demonstrated through the example of the electric doorbell. Here we also link these different discount rates to different perspectives, namely the perspective of a private investor and the perspective of the society (given figures are indicative). An average electric doorbell in Europe consumes 3 W of electricity due to the transformer that is constantly switched on. Assuming that about a quarter of the over 200 million households has an electric doorbell, this equals about 1.3 TWh of annual electricity consumption, which – when assumed to be produced by baseload coal fired power plants (e.g. 200 MW) – could imply over 1 Mtonne of CO_2 emissions per year. The proposed policy measure is a ban on the sales of electric doorbells with any stand-by losses. The assumptions and assessment are summarised in Table 2.

Table 2. Example of a cost-benefit assessment of a ban on electric doorbells with stand-by losses

Variable	Unit	Societal perspective	Private perspective
Cost of measure	€	30	
Technical lifetime	Yr	20	
Electricity savings	kWh/yr	26	
Cost of electricity	€/kWh	0.15 (excl. taxes)	0.20 (incl. taxes)
Discount rate	€/kWh	4%	17.5%
Annual discounted cost	€/yr	-2.2	-5.5
Annual savings	€/yr	3.9	5.3
Net savings	**€/yr**	**1.7**	**-0.2**

From a societal perspective a ban on doorbells with stand-by losses could be justified in this simplified case (assuming no other costs, e.g. administrative costs). But from the private perspective, taking a higher subjective discount rate of 17.5%, the policy option would not be justified. The savings don't outweigh the higher annualised investment costs. And this is what can be observed in reality: energy will seldom be part of the equation. This raises the following questions:

- Who takes the investment decision? For replacement in existing privately owned houses this will be the household itself. But for new buildings this will be the project developer, for housing cooperatives this will be the cooperative. Doesn't this influence the value for the discount rate that should be used in the comparison?
- Doesn't the policy option, in this case a ban which eliminates an alternative investment opportunity, directly affect the subjective discount rate?

Applying (only) high discount rates will disguise feasible policy options for high efficiency.

3.3 The cost-optimality example

In the following we illustrate the impact of high discount rates on decisions about suitable energy efficiency levels with the example of "cost-optimality calculations". According to Article 4 of the Energy Performance of Buildings Directive (EPBD), "Member States shall take the necessary measures to ensure that minimum energy performance requirements for buildings or building units … or building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are replaced or retrofitted, are set with a view to achieving cost-optimal levels." The calculation methodology is defined in Commission Delegated Regulation (EU) No 244/2012 [European Parliament and the Council of the European Union (2012)] and reflects the above explained global cost approach. Article 5 of the EPBD requires Member States to report their cost-optimality calculations. The German calculations are documented in [Offermann et al., 2013]. For our illustration we modify some of the German results for new built multi-family homes. The result of this exercise is shown in Figure 1.

The points in the two graphs show the global cost for a number of different energy efficiency measures in buildings and their resulting specific primary energy demand. The solid black vertical line is the current requirement (but which in Germany has been set using a private perspective), the green lines illustrate 12.5% or 25% lower than current maximum allowable primary energy demand (= minimum energy performance requirement), whereas EH70, EH55 and EH40 symbolise 70%, 55% or 40% of the current maximum primary energy demand. As an example we performed the macro-economic calculations (societal perspective) for new-built multi-family buildings with a real discount rate (excluding inflation) of both 0% (upper graph; original values) and 15% (lower graph, newly calculated values).

The result is striking. Similar results would follow for other building types, for renovation and also for the micro-economic perspective (private perspective): *low discount rates suggest high energy efficiency alternatives (upper graph) as minimum energy performance requirement, while high discount rates pull low energy efficiency alternatives towards lower global cost and make them look appropriate for defining minimum energy performance requirements.*

More concretely, in this example taking a discount rate of 0% the *primary energy* demand (approx. 28 kWh/m^{2}a) having least global cost is less than half of the result when taking 15% (69 kWh/m^{2}a). Note that no alternatives having even higher primary energy consumption were part of the German cost-optimality study, thus it might be that – applying a 15% discount rate - alternatives with even lower global cost but having primary energy demands of even more than 69 kWh/^{2}a might appear to be cost-optimal. In a nutshell: the low discount rate would suggest to significantly decrease the maximum allowed primary energy consumption (i.e. to significantly increase efficiency) while the high discount rate would suggest to continue with business as usual.

The higher the discount rate the lower the ambition of minimum energy performance requirements.

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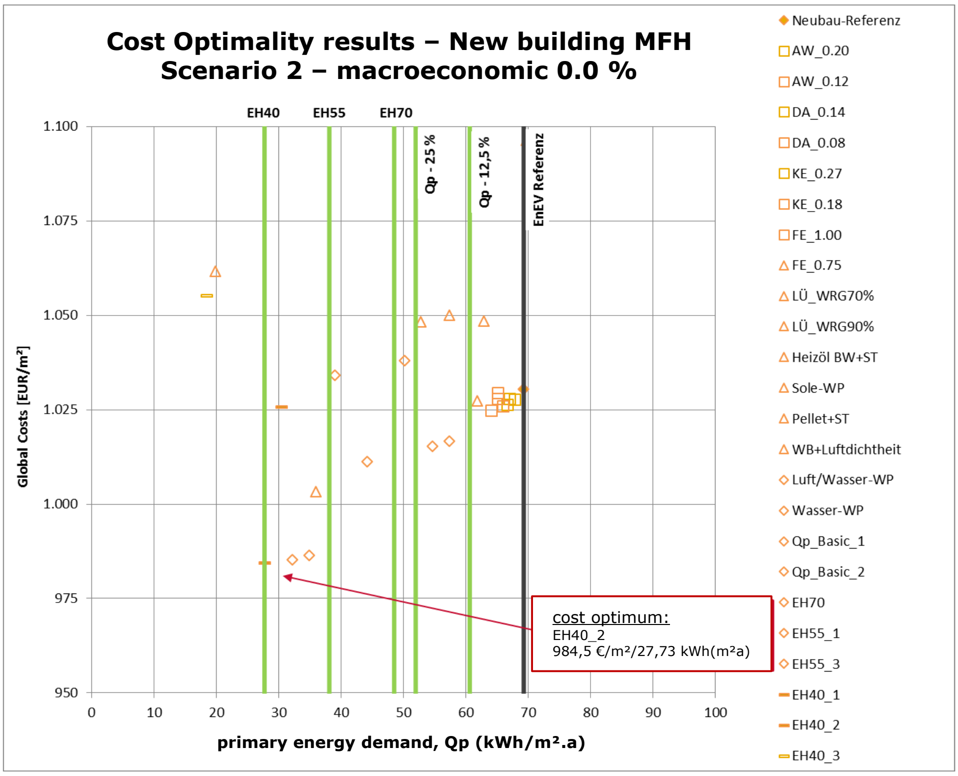

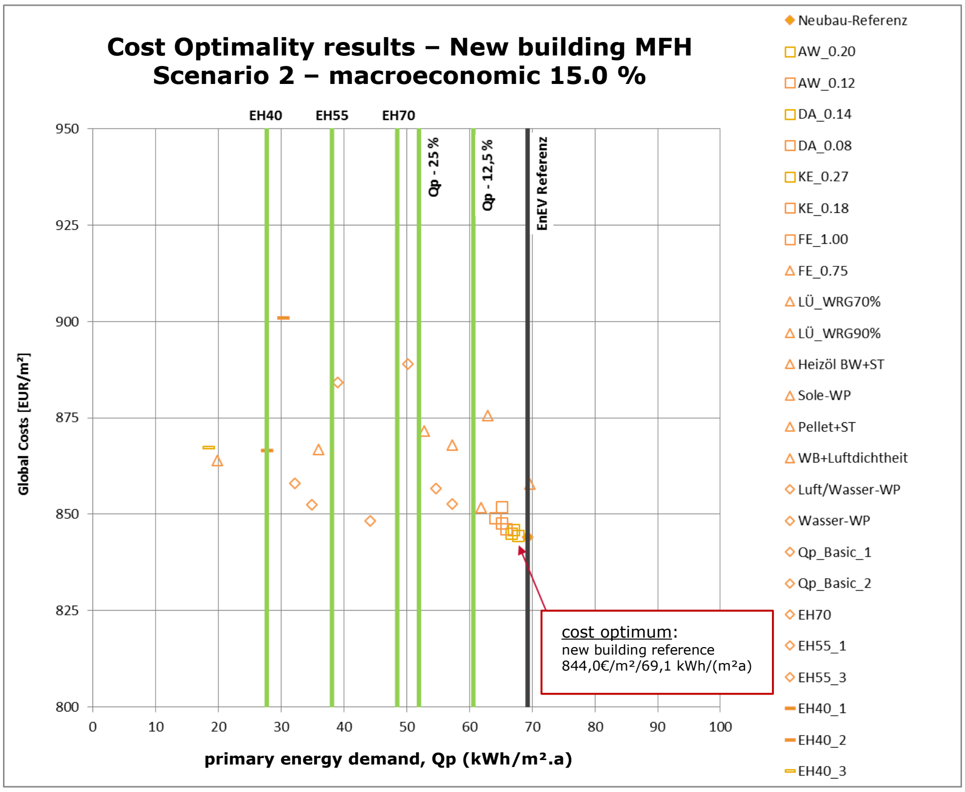

Figure 1. Erosion of minimum energy performance requirements through high discount rates

4 Which discount rates to use?

In this chapter we briefly analyse different sources that suggest taking certain discount rates.

4.1 Evidence from recent studies on discount rates in EU Impact Assessment

Recently three short but profound studies have dealt with the topic of proper use of discount rates in Impact Assessments. We only highlight the key findings:

Pollitt, Hector; Billington, Sophie (2015): The Use of Discount Rates in Policy Modelling.
The study's major finding is that the recent EC Impact Assessments do *not* follow the usual practice in modelling, which is "to apply a higher 'stage one' discount rate to model the decision-making behaviour of economic agents, and a lower 'stage two' rate – typically a social rate – to evaluate costs and benefits."

Steinbach, Jan; Staniaszek, Dan (2015): Discount Rates in Energy Systems Analysis.

- The authors clearly state that *social* discount rates need to be applied for evaluating total costs and benefits of energy systems. Based on an application of the "Ramsey formula"[15] the social discount rates for EU Member States can be assumed to be in a range between 1% – 7%.
- Individual discount rates are applied to model investment decision making, reflecting the expected return of an investor.
  - Discount rates should be differentiated according to different investors.
  - For households, discount rates should reflect the market price of capital. A differentiation of discount rates by socio-economic parameters of individual investors is recommended.
  - Literature (except assumptions made for modelling in PRIMES) generally states lower discount rates for households than for commercial and industry sectors.
    - Commercial and industry: **6% – 15%**
    - Households: **3% – 6%**
- The use of *high discount rates to represent non-economic barriers and bounded rationality (like e.g. done in PRIMES modelling) in decision making is not suitable*. Rather behavioural models should be used which consider individual decision criteria as well as barriers to energy efficiency *explicitly*.

[15] For a more detailed description see sub-heading "social discount rate" in chapter 4.5.2.

Dupuy, Max (2015): Hidden Barriers to Efficiency. The Treatment of Discount Rates and Energy Efficiency Costs in EU Policy Scenarios.
This study is an analysis specifically about the EC's January 2014 Impact Assessment Communication and accompanying documents [European Commission (EC), 2014a, 2014c]. The authors state specifically that the use of relatively high discount rates hampers scenarios with more ambitious energy efficiency policies, which is a general flaw not linked to the use of a specific model. They report Impact Assessments from the US Department of Energy, which uses a "true" discount rate of 4.5% rather than much higher "implicit" discount rates derived from observed purchasing behaviour. They also report an assessment of EU policies undertaken with the E3ME model in 2013, in which a discount of 8% was applied in a "low energy efficiency policy intensity" scenario, whereas 4% was used for "a high energy efficiency intensity scenario".
Altogether these rates are much lower than the ones applied in recent EC Impact Assessments of energy policy options, which the authors consider to be inappropriately high and little justified. They suggest using high "implicit" business-as-usual discount rates in the absence of strong policies to support energy efficiency, whereas lower "true" discount rates, reflecting the true opportunity cost of capital should be used in scenarios that consider strong energy efficiency policies.

4.2 Evidence from EC documents

Impact assessment of EU policies is not a random process but there are guidelines for systematically assessing them, including energy and climate relevant policies.

Impact Assessment Guidelines
For all recent impact assessments the Impact Assessment Guidelines SEC(2009)92 from 15 January 2009, including annexes, were in place [European Commission (EC), 2009a] and [European Commission (EC), 2009b]. Relative to discount rates some citations from the Annex are most instructive [italics used by us for emphasis]:

- "When 'discounting' is used, it should be applied both to costs and benefits. ***You should use a discount rate of 4%.*** This discount rate is expressed in real terms, taking account of inflation. You should therefore apply it to costs and benefits expressed in constant prices."
- "This rate broadly corresponds to the average real yield on longer-term government debt in the EU over a period since the early 1980s. *For impacts occurring more than 30 years in the future, the use of a declining discount rate could be used for sensitivity analysis*, if this can be justified in the particular context."
- "*For some cases involving very long horizons – such as the effects of climate change – it may be appropriate to use a lower discount rate.* This might be justified by the longer-term implications of sustainable development and in particular, the need to take proper account of the preferences of future generations."

  These guidelines thus do not differentiate between the discount rate to be used for "Stage 1" or "Stage 2" of the calculation.

Better Regulation Guidelines

The above mentioned Impact Assessment Guidelines have recently been replaced by the Better Regulation Guidelines SWD (2015) 111 final from 19 May 2015 [European Commission (EC), 2015]. These new guidelines include a "toolbox", with chapter 8 summarising methods to identify, assess and quantify costs and benefits. Here "Tool #54" explains the use of discount rates. Again some citations are instructive:

- "The social discount rate is the rate most used in Impact Assessments, as these normally consider costs and benefits together from the point of view of society as a whole (rather than from the point of view of a single stakeholder group). The recommended [real] social discount rate is 4% [costs/benefits]".
- "In general, it is not appropriate to use alternative social discount rates, as using the 4% rate consistently in Impact Assessments and an evaluation ensures coherence and comparability." Nevertheless the guidelines suggest to consider even lower social rates in sensitivity analysis when it is about long-time frames, in order to appropriately include future generations in today's decision making.

This is broadly in line with the former Impact Assessment guidelines, except that now the guidelines clarify that 4% refers to a *social* discount rate, as it is about assessing costs and benefits of policies for the society rather than for individuals. Up to this point nothing like "stage 1" or "stage 2" has been introduced. Yet there is another chapter "Costs from the perspective of private capital and economy wide modelling" that adds some new aspects:

- About the *perspective of private capital*:
  - "The social discount rate is *only* used, therefore, when looking at issues from the societal point of view."
  - "A higher discount rate should be used when trying to assess the *behaviour* of a company in respect of an *investment decision*."
  - "Higher discount rates may also apply for households when *deciding* on whether to make an investment due to a range of factors: such as finance costs and other behavioural constraints like split incentives (e.g. landlord/tenant), short time horizons, risk averseness, information asymmetries or other obstacles or barriers."
  - For regulated sectors, the financing cost for that sector should be used.

- About *economy wide modelling:*
  - This "should be *complementary* to assessments made from the point of view of society".
  - "Economy-wide modelling … is best achieved using a sector-specific discount rate for annuitizing capital costs."
  - Useful when policy options have cross-sectoral impacts
  - Informs about the "affordability of a given policy for economic actors to be identified which can be used **in addition to or, in certain cases where it is a cross sectoral policy, instead of the usual determination of societal costs."**
  - "Models can, therefore, be used to simulate 'real world' **behaviour** …"

- "This can be … done through … partial equilibrium modelling tools that look at the economy wide measures but **use exogenously determined private discount rates** that reflect risk aversion, opportunity cost and other barriers."
- "A common example is energy system modelling where sector-specific discount rates can be much higher than the 4% … "
- "If private discount rates are adapted according to different policy options, the links between the market failures targeted by the policy option and the impact on the sector-specific discount rate should be clearly demonstrated and documented."
- "Lower discount rates should only be used if it can be shown that a policy option can indeed address the relevant market failures, …"

The following observations can be made by from the information given about those two generations of impact assessment guidelines:

- The 2009 guidelines only included the recommendation to apply a 4% (social) discount rate for ex ante impact assessment of policy options. There were no recommendations on how to represent real world behaviour via the discount rate. Therefore previous impact assessments like the ones published in 2014 seem to have not fully been in line with those guidelines, as they applied, as explained above, much higher discount rates.
- As to the perspective of private capital in the new guidelines, the use of higher discount rates is clearly related to modelling of decision *behaviour* – nothing like that was part of the previous Impact Assessment Guidelines.
- The study "Assessing the Costs and Benefits of Regulation" [Renda et al., 2013] which was to provide input to the revision of the 2009 Impact Assessment Guidelines leading to the Better Regulation Guidelines, did not mention the use of higher discount rates, neither for mimicking decision making behaviour nor for determining system cost. On the contrary it stated that "4% appears very balanced when it comes to recognising long-term benefits." It also did not mention "economy wide modelling".
- Rather confusingly, on the one hand the Better Regulation Guidelines require that economy-wide modelling should be *complementary*, on the other hand it opens up the opportunity to use it *instead* of the usual determination of societal cost. The explanation provided for this possibility is rather weak and there are a number of issues with it:
    - It remains unclear why *partial* equilibrium models, which by definition focus on one sector of the economy, should be specifically suited to model *economy-wide* impacts, i.e. affecting multiple sectors.
    - As *exogenously* (= coming from outside the modelled sector) determined discount rates are used, it is also unclear how policy measures affecting this sector could give an explanation for changes of these exogenously determined discount rates. But such explanation is explicitly required by the guidelines for the case of adapting those discount rates as a consequence of policy measures.
    - **There is no explanation if such adaptations should affect the subjective discount rates used for decision making *and/or* for accounting of system costs.** A clarification about this very crucial aspect therefore is urgently needed.

  - Above all, the consequences remain unclear of what moving away from a societal perspective to an economy-wide perspective means for the overarching policy target of maximising well-being from a *societal* perspective, which inherently needs to consider the long-term sustainability of a society.
- The wording used in the Better Regulation Guidelines is surprisingly similar to the explanations given around the 2030 framework assessment which has been done based on PRIMES simulations and the PRIMES model descriptions. The chapter on "economy-wide modelling" seems to provide an ex post explanation for the way recent impact assessments have been conducted as these have not been in line with the 2009 guidelines which were in place by the time when the 2030 framework assessments had been conducted.

EC "Guide to Cost-Benefit Analysis of Investment Projects - Economic appraisal tool for Cohesion Policy 2014-2020"

The EC "Guide to Cost-Benefit Analysis of Investment Projects - Economic appraisal tool for Cohesion Policy 2014-2020" [Sartori et al., 2014] explains which discount rates are to be used in cost-benefit analysis of projects which are financed by the European Structural and Investment Funds. Regardless of which perspective is taken, very low discount rates are proposed:

- Financial Discount Rate (FDR): "The FDR is the opportunity cost of capital and is valued as the loss of income from an alternative investment with a similar risk profile." "The European Commission recommends that a **4 %** discount rate in real terms is considered as the reference parameter for the real opportunity cost of capital in the long term." Values other than 4% may be justified, depending on macroeconomic conditions in a Member State, and/or the type of investor/sector concerned.
- Social Discount Rate (SDR): This rate has to be applied in the so-called "economic analysis" which is to appraise the project's contribution to welfare. Therefore the SDR reflects the social view on how future benefits and costs should be valued against present ones. The benchmark used is **5%** for projects in Cohesion countries (Bulgaria, Croatia, Cyprus, the Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia and Slovenia) and **3%** for other Member States. Other rates may be justified, preferably based on the social rate of time preference.[16]

[16] This may be calculated applying the „Ramsey formula", see (Steinbach and Staniaszek, 2015) and (Hepburn 2007).

4.3 Evidence from selected EU countries

4.3.1 France

For its investment policy, the French government uses a **societal discount rate of 4%** (for instance when forecasting investments in energy generation assets). [Cour des comptes, 2013] [ADEME 2006-04]. Beyond 30 years this rate falls to **2%** [Hepburn, 2007].

Official documents assessing the efficiency of tax rebates encouraging investments in energy efficiency use differentiated discount rates according to the type of households and housing in their modelling [DGEC et al., 2011]. In those cases, the discount rate for homeowners in individual housing (propriétaires occupants en maisons individuelles) is 7%, while it is 10% for homeowners in collective housing (propriétaires occupants en maisons collectives). For landlords, the discount rate is 35% in individual housing and 40% in collective housing, *reflecting lower willingness to invest in energy savings* due to the split incentives problem[17]. These discount rates have been estimated and result in a weighted average discount rate of energy efficiency investments in **housing** of **21%**. Clearly this is about **"subjective" discount rates** used to predict decision behaviour rather than "true" discount rates or opportunity costs of capital of investors.

4.3.2 Germany

There is no central guidance on which discount rate should be used in the assessment of energy and climate policies in Germany. [Steinbach and Staniaszek, 2015] pointed out, that most studies on behalf of the government use discount rates for the macro-economic or **societal perspective usually** being **just below 4%**, and **in sensitivity analysis between 0 and 7.5%**, in some cases explicit reference is made to long-term government bonds. As discount rates significantly determine the results of such studies, they are usually explicitly discussed and fixed in the early stages of such studies; therefore the discount rates used in those studies serve as a good proxy for the "official" approach in Germany.

Some studies use discount rates both for analysing the societal perspective and for analysing a private perspective. In these cases the individual rate is often taken to **mimic investment decision behaviour** while the macro-economic evaluation of these investments is calculated using the lower societal rate. Generally **households** are assigned lower discount rates like **4%**, whereas **commercial actors** due to their higher profit expectation are assigned **7% to 10%.**
Cost-optimality calculations for determining the minimum energy performance requirements for buildings were conducted with real rates of **1.3% and 3.5% for the "financial" (private/commercial) perspective**, and with **0% and 3% for the "macroeconomic" (societal) perspective**. The "3.5% financial" perspective was chosen to be the decisive one for comparing actual requirements with cost-optimality results.

[17] For more details see chapter 4.5.2.

4.3.3 Netherlands

The Dutch General guidelines for societal cost-benefit analysis also use a **societal perspective** and use **typically real discount rates of 4 to 5.5%.** The rates are set by the Dutch Cabinet, they are hence normative.
In the general guidelines for societal cost-benefit analysis, CPB/PBL, 2013 (in Dutch), Section 7.4.2, p. 110, it is stated that:
The societal cost-benefit analysis (SCBA) uses real risk-free discount rates (2.5%) with a measure-specific premium reflecting macro-economic risks. Measure-specific means that the risk-premium can differ per cost- or return-post. (…) Up to now it has appeared to be impossible to determine the measure-specific premium for macro-economic risks for concrete cases. It is hence common practice to use a default value of 3% for the macro-economic risk. The net present value in the base year of costs and returns are hence calculated using a discount rate of 5.5% (2.5% real risk-free + 3% premium for macro-economic risk). If it can be substantiated that the macro-economic risk of the measure or the project (element) deviates from the national average, also a project-specific premium can be applied.

General guidelines for societal cost-benefit analysis, CPB/PBL, 2013 (in Dutch), Section 10.3.2, p. 158:
The 3% macro-economic risk premium of a specific project or measure can be reduced to 1.5% if the following two conditions are being met: (i) the project affects negative external impacts; and (ii) these impacts are irreversible.

4.3.4 United Kingdom

The Green Book of the UK Treasury also uses a social discount rate, of (maximum) **3.5%** [HM Treasury, 2011] reflecting the '*social* rate of time preference (SRTP) which is the rate at which society values the present compared to the future. [Department of Energy and Climate Change, 2014a, 2014b] also suggests to adjust cash flows to account for risks rather than adjustment of the social discount rate.
More concretely the Green Book adjusts discount rates according to the distance from now:
The STPR to be used as the real discount rate is 3.5% for appraisal periods of 0-30 year, for 31-75 yr: 3.0%; for 76-125 yr: 2.5%; for 126-200 yr: 2.0%; for 201-300 yr: 1.5% and >301 yr: 1.0%.
The UK is the only country in the EU which systematically bases discounting on scientific grounds leading to decreasing discount rates for very long terms as a consequence of increasing uncertainty about the future [cf. Hepburn 2007].

4.3.5 Conclusion on Government guidelines

- Government guidelines, if they exist, usually prescribe the use of a **societal, macro-economic perspective** and hence *prescribe* the use of **social discount rates** for impact assessments and societal cost-benefit analysis. This is clearly different from recent Commission practice, although it is in line with the 2009 Guidelines, and with the parts of the 2015 Guidelines that discuss the societal perspective.

- The discount rates differ per country (and the rates can change over time). For the countries reviewed above the range is **1.7%-6%.** The discount rate is a **normative** parameter set by Government or individual Ministries.
- From his analysis of discount rates guidance in several OECD countries [Hepburn, 2007] additionally draws the following conclusions and recommendations:
    - In case there is a conceptual foundation for the discount rate it usually is the *social rate of time preference* (SRTP) as applied in the UK. When properly applied this only allows for relatively small differences between EU countries.[18]
    - In many cases it is derived from a risk-free market rate, which is an inappropriate proxy from a theoretical point of view but practically usually close to the SRTP.
    - Within Europe many countries have adopted EC guidance (4%).[19]
    - As sometimes different discount rates can be observed across different government departments, there should be central mandatory rules on discounting rather than "guidelines" in each country.
    - Social discount rates should be estimated according to the social rate of time preference using the "Ramsey formula".[20]
    - The social discount rate should explicitly account for uncertainty in future macroeconomic conditions concretely resulting in a discount rate that declines with time.

4.4 Evidence from Member States' cost-optimality reports

According to the Energy Performance of Buildings Directive each Member State has to justify its minimum energy performance requirement for buildings (different building types, new, retrofit) by means of cost-optimality calculations. An example was given in chapter 3.3, highlighting the very strong impact the chosen discount rate has on the result. The corresponding delegated regulation [European Commission (EC), 2012] requires Member States to do the calculation both from a financial (= private) and a macroeconomic (= social) perspective. For the macroeconomic perspective a sensitivity analysis on at least two different rates must be done, one of which shall be **3%** expressed in real terms.[21] Yet, in practice *Member States are free to choose the perspective and the discount rate* for comparing the results of cost-optimality calculations with their existing minimum performance requirement. Therefore it is very informative to take a look at those discount rates, the ones Member States actually applied in their individual cost-optimality calculations (Figure 2).

[18] (Steinbach and Staniaszek, 2015) actually calculate the range for EU countries and arrive at a maximum justifiable bandwidth of 0.5% to 6.9%, with average values ranging from 2.6% to 3.9%.
[19] The EC 2005 Impact Assessment Guidelines 2005, SEC(2005)791 in place during Hepburn's study also recommended a 4% discount rate.
[20] Cf. chapter 4.5.2, sub-heading "social discount rates".
[21] There is some confusion, as the guidelines (European Commission (EC), 2012) accompanying the delegated act ask for 4%; yet the delegated regulation's 3% is the legally binding figure and should be used. The Commission should consider issuing a correction (erratum) to avoid further confusion.

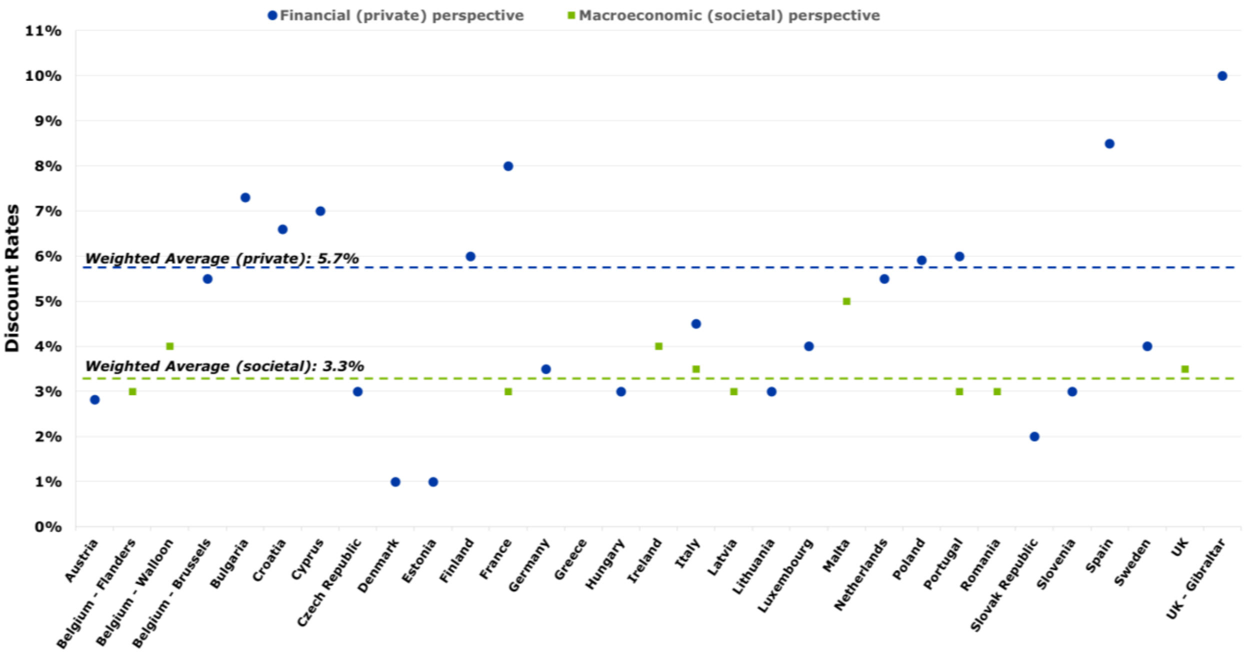

Figure 2. Discount rates applied by EU Member States in cost-optimality calculations

The result is very clear. The vast majority applied discount rates between 3% and 6%. About one third of the Member States chose to apply the social perspective, where most Member States went for a discount rate of 3%. Note that the UK consequently followed the approach of chapter 4.3.4 of the present study by applying a social discount rate of 3.5%, demonstrating the benefit of having central rules for the use of adequate discount rates. On average, calculations were done with a social discount rate of 3.3% or a private discount rate of 5.7% respectively, both resulting from weighing the numbers shown in Figure 2 with a Member State’s share in the EU’s total building construction production. All values are remarkably lower than the ones recently used in EC Impact Assessments, although both cost-optimality and impact assessments were being conducted almost concurrently.

4.5 Evidence from literature including comparable impact assessments

Apart from the evidence presented before we have also carried out an in-depth review of literature dealing with similar impact assessments but more specifically with the question of what is the “right” discount rate.

4.5.1 Results from similar impact assessments

In October 2014 the results of three studies were presented that had been commissioned by the German Federal Ministry for Economic Affairs and Energy in the advent of the decision on the EU’s 2030 climate and energy framework. The major question was which policy framework would support the most cost-efficient pathway offering the highest return on investment with a view to achieving the 80%-95% emission reduction target by 2050. Concretely the question was analysed whether a *triple* set of binding targets – 40% GHG reduction, 30% energy efficiency and a 30% share of renewables would be more cost-effective than a path with a *single* GHG target and an ETS-only approach [BMWi, 2014]. Three institutions were asked to conduct and compare impact assessments for these two settings.

- National Technology University of Athens, doing a new PRIMES scenario for 40/30/30 [Capros et al., 2014].
- Fraunhofer ISI / TU Vienna [Held et al., 2014]
- Prognos AG / Ernst & Young [Deutsch et al., 2014]

All studies drew a similar conclusion: *an enabling policy framework* featuring a 40/30/30 triple target and a set of tailored instruments *would increase predictability for market actors, and thus reduce investment risks and cost of capital for renewable energy and energy efficiency*.
Concretely, Prognos AG estimated the cost of capital for renewable energy in a 40/30/30 Europe to be *2% lower* than in a setting with GHG target and ETS-only.
The new PRIMES model run resulted in €20 billion lower total annual energy system cost than in the previous GHG40/RES30/EE30 scenario without dedicated policy framework, thus arriving at the *same* system cost as in the previous most cost efficient GHG40 scenario, which lead to 27% energy efficiency and 25% renewable share.
Fraunhofer/TU Vienna results are even more favourable for the 40/30/30 targets, as they state up to €21 billion reduction in annual total energy system cost by 2030 *compared to the GHG40 scenario*. Additionally Fraunhofer/TU Vienna concludes that without adding an energy efficiency target, system costs would not fall significantly; only adding a 30% renewable target would increase system cost slightly; this followed from a detailed bottom-up analysis for renewable energy systems potentials with high-spatial and temporal resolution. [Capros et al., 2014] do not convey the detailed discount rates used for the new scenario and other parameters that may have been adapted in PRIMES, yet it can be assumed that above mentioned enabling framework amongst others was translated into lower discount rates for the decision making part. Fraunhofer/TU Vienna used the following "true" discount rates: power sector: 6.5%-7.5%, household space heating & hot water: 3.1% to 3.7%; household appliances: 2% to 6%; tertiary space heating & hot water: 4.7% to 5.4%, tertiary appliances: 5% to 15%, industry: 3% to 15%.
On average these Fraunhofer/TU Vienna rates are significantly lower than the default values used in PRIMES simulations (cf. Table 1); furthermore compared to those PRIMES default values households have *lower discount rates than industry*. This is because decision behaviour is simulated using a behavioural model instead of using subjective discount rates for mimicking behaviour.

This exercise underlines that results of impact assessment depend as much on careful "translation" of policy options into sensible modelling parameters as on the applied model itself.

4.5.2 Literature on discount rates

The whole discussion in literature about discount rates can be divided in three major clusters:

- Behavioural discount rates
- Real, market based discount rates
- Social discount rates.

Behavioural discount rates

The major driver for decades of research about behavioural discount rates is the so-called "energy efficiency gap" or "energy efficiency paradox" [Ameli and Brandt, 2015]. This is the underinvestment in "clean technologies", being the difference between *actual* purchases on the market and *potential* purchases, which in theory are cost-effective when applying real market based discount rates. From all the investments having a positive net present value when calculated with market interest rates but which are not realised on the market, a hypothetical "implicit" discount rate can be calculated which may be significantly higher than the market discount rate.[22] Values up to 300% have been found. Several terms can be found in literature for the "implicit" discount rate, like "subjective", "individual", "personal", "latent", "hidden" or "behavioural" discount rate. Note that "implicit" discount rates are nothing you can get directly by means of asking investors; in most cases they have been calculated from observations of actual decision making, in few cases from information about the willingness-to-pay; that's why they are called "implicit". The other way around this could be interpreted as "intangible cost" that virtually increases real cost to what previously has been referred to as "perceived cost". In order to close the "efficiency gap" there has been a lot of research about the reasons for its existence. Note that [Ameli and Brandt, 2015] find that reasons for (under)investment in renewable energy technologies are similar to those for energy efficiency technologies.
This is a non-exhaustive list based on [Ameli and Brandt, 2015], [Hedenus et al., 2013], [Sartori et al., 2014], [Neij et al., 2009], [Mundaca et al., 2010], [Daziano, 2015], [de La Bruslerie, Hubert, 2015], [Lazar and Colburn, 2013], [Geller and Attali, 2005]:

- Consumers undervalue future gasoline/energy cost compared to initial investment when deciding between alternatives with different efficiencies. Overall there is much higher responsiveness to initial investments than to subsequent savings. This is e.g. because people simply have a time preference and because consumers are risk-averse and loss averse: they see a certain, irreversible expenditure for an unfamiliar technology compared to uncertain future energy cost savings. This also leads to delays and slow diffusion as consumers tend to wait until they feel more certain.
- Engineering savings may be overestimated due to re-bound, behavioural factors, etc.
- Engineering estimates (only including installation and energy cost) might underestimate perceived cost, which include transaction cost (e.g. time needed for getting information, selection of equipment, supervising installations, learning how to operate …).

[22] This is the (higher than real market) discount rate where the NPV of all investments not taken is just 0.

- While on average energy efficiency investments may be profitable, they may not be for parts of the population.
- Market failures, specifically energy prices do not reflect the external costs to society.
- Especially low-income households may face capital constraints, i.e. restricted access to credit. There is profound empirical evidence for this factor.
- Too high perceived credit risk of banks due to limited know-how about energy efficiency investments.
- Principal-agent or split-incentive problem: the one who invests is not the one who benefits.
- Information deficiencies: generally there is poor knowledge about actual energy cost, potential savings and extremely limited understanding about financial assessments like payback calculations; even if there is, consumers mostly don't apply it.
- There are lots of decision criteria apart from economics (let alone energy costs as one part of the overall economics of the measure), like design, comfort, brand, functionality, reliability and environmental awareness and others [Neij et al., 2009].
- All in all there is irrational behaviour, being adverse to rational choice theory, partly because people apply over-simplistic decision rules (heuristics) due to bounded rationality.

Responding to this long list of potential explanations for the energy efficiency gap, [Ameli and Brandt, 2015] present a systematic overview of corresponding policy responses:

Table 3. Main barriers to energy efficiency and policy responses (source: [Ameli und Brandt, 2015])

Barriers to energy investment	Policy responses
Market Failures	
• Energy prices	• Pigouvian tax[23]
• Capital constraints	• Financing loan, direct subsidies, tax credits
• Split incentive problem	• Law allowing owners to increase the rent after implementing EE, information programmes
• Information problems	• Information programmes (peer-comparison feedback, nudge), energy standards/labels
Behavioural issues	
• Bounded rationality • Heuristic decision-making	• Information programmes (peer comparison feedback, nudge), energy standards/labels

The sobering conclusion from the latest research of [Ameli and Brandt, 2015] is that "the size and even the existence of this underinvestment are still questioned. … What barriers are most relevant and how they compare to each other might be empirically investigated in future research. Targeted policies are required to address specific barriers for different groups of consumers".

[23] A Pigouvian tax is a tax on negative externalities. Raising it would internalise these externalities in the price of energy and remove the too- low-price that leads to market failure.

The default subjective discount rates used in PRIMES for mimicking decision behaviour lie within the huge range of what literature provides. Altogether we need to state that literature reveals very little consensus about discount rates that should be used to predict consumer's decisions about investments in energy efficiency. [Chunekar and Rathi, 2012] arrive at the same conclusion.

Consequently [Mundaca et al., 2010] confirm that "discount rates in the context of efficient-technology choice need to be better understood; otherwise, their usefulness will continue being questioned. This evaluation challenge tells us that more research is needed to better understand how current energy efficiency policy instruments actually reduce or overcome the market and behavioral failures that drive the use of high implicit discount rates." In [Neij et al., 2009] the same authors specify that "in order to better capture all, or just the key, determinants of the selection criteria for energy-efficient technologies, we need to further enhance models for energy use scenarios. In turn, such models are also essential for the evaluation of potential and actual policy instruments for energy efficiency."

Most interestingly [Neij et al., 2009] question whether implicit discount rates are the most suitable way to reflect "irrational" decision behaviour as in the end a rational choice approach is tweaked for irrational choices; therefore they suggest agent-based modelling to be further investigated in order to complement insights into complex technology choices of households.

[Pollitt et al., 2010] go in the same direction when explicitly for the case of long-term policies saying that "it is questionable whether individual discounting models should be translated to the intergenerational context. Such an approach does not appear to be compatible with a sustainable model of the macroeconomy."

For us this is first to stress that recently the appropriateness of using implicit or behavioural discount rates for explaining or predicting decisions about energy efficiency investments has been questioned. Furthermore, when discount rates have been used for that purpose, they *only* have been used for that purpose: Behavioural rates are *not* meant for the economic evaluation of these choices from a wider societal perspective.

Real, market based discount rates

As mentioned above, subjective discount rates of agents may significantly differ from their actual cost of capital. "This cost is often expressed as the weighted average cost of capital (WACC), which represents the relative weight of return on equity and cost of debt with different risk." [Deutsch et al., 2014] The elements of WACC usually are inflation, preference in time (people prefer to have 1 EUR today to having it tomorrow) and risk. The WACC should therefore reflect the actual risk associated with an investment. The WACC for a particular measure will differ per stakeholder, financial structure (e.g. debt/equity ratio) and country. These types of differentiations are often not included in energy models for practical reasons. As an example [Lazar and Colburn, 2013] mention utility financed demand-side-management programmes. As these are re-financed by ratepayers, in this case the utility faces very low risks, which for this type of investment should lead to a discount

rate below the average WACC of the utility. To avoid confusion, also the WACC can be given in "real prices", i.e. related to a base year. In this case inflation is excluded.
As WACC is still a rate based on preferences of *individuals*, some literature questions the applicability for the evaluation of long-term policies aimed at *societal* well-being [Pollitt et al., 2010].

Impact of policies on real or behavioural discount rates
There is limited empirical evidence on the impact of policies on cost of capital. An upcoming study [Ecofys et al, 2015, upcoming], DIACORE, financed under the Intelligent Energy Europe Programme, will present a methodology to quantify country-specific costs of capital for onshore wind energy in all EU Member States (both equity and debt). This methodology was then used as a starting point for validation by different stakeholders across Europe. The weighted average cost of capital (WACC) varies from 4-5% to 12%, which is a combination of notably country, market and policy risk. As all Member States have renewable energy policies, the WACC for a 'no-policy' situation could not be quantified. Between similar countries (in terms of country and market risk), with different main policies or with a different history of renewable energy support, the WACC differences are in the order of 2-3%.

Social discount rates

[Hepburn, 2007] provides a most instructive overview as to the state-of-the-art research around social discount rates.

- Hepburn recalls that discounting implies a lower weight to future costs and benefits than to present costs and benefits. This inevitably "can appear to offend notions of sustainable development and the interests of future generations", thus it reflects "our most fundamental views of the future" and "how we treat future generations". Nevertheless he also points out that in most cases a discount rate of zero, i.e. non-discounting, is not an adequate solution either and it also does not necessarily lead to greater environmental protection. Below, we briefly summarize his scientific derivation of social discount rates, which e.g. has been taken up in the UK (see chapter 4.3.4).
- There are two reasons for applying a positive (i.e. >0%) discount rate. "First, people prefer to have good things earlier rather than later". Second, due to the productivity of capital, savings will allow increasing consumption with time. Therefore the following formula is suggested for social discounting (see also [Steinbach and Staniaszek, 2015]):
  $s = \delta + \eta g$
  δ: *utility* discount rate (or the rate of pure time preference),
  η: elasticity of marginal utility,
  g: is the rate of growth of consumption per capita.
- Note that s is for discounting *future cash flows* while δ is for discounting *future utility*. From an ethical point of view it is hard to find good reasons for deviating from $\delta = 0$. The only acceptable reason would be quite improbable events that endanger the survival of mankind, like an asteroid striking the Earth. If such risk is accepted, a small discount rate like Stern did with $\delta = 0.1\%$ may be applied. Still ηg may easily be positive, mainly depending on the

growth rate of an economy and thus justifying a positive social discount rate without being ethically questionable.

- Due to this concept the value of market rates may be a good approximation for the social discount rate, but still they have a fundamentally different conceptual background as they are based on individual preferences; thus the above mentioned formula should be used like in the UK, rather than any market rates.
- There are no arguments pro applying different social discount rates for different types of projects.
- Finally, without going into the details, [Hepburn, 2007] shows that uncertainty about future economic conditions logically leads to a declining “certainty-equivalent discount rate”, again like applied in the UK.

5 Conclusions and recommendations

From previous analysis and interim findings we draw the following final conclusions. The order of conclusions does not reflect importance, but we deem it to best reflect the train of thought.

1. The choice of discount rates has a significant impact on the evaluation of policy options.

We have pointed out the striking impact of discount rates on the evaluation of different energy and climate policy options. The higher the discount rate the less attractive high-energy-efficiency investments and supporting policies get.

2. The use of discount rates for modelling of individual investment decisions and for the evaluation of energy system costs from a societal perspective must be kept apart. This is currently not the case.

This is our major concern with recent Commission practice.

There is no plausible explanation in the supporting documents why as a default in PRIMES modelling the *same* high "subjective" discount rates are used for the calculation of the energy system costs from a societal perspective as for predicting individual decision making. By definition "subjective" discount rates are bound to individuals, reflecting individual preferences and restrictions. Society as a whole, which in fact is the subject *and* object of policy making – where policy makers are just the ones representing society for making decisions about that society on its behalf – has utterly different preferences, restrictions and time horizons. In this context we'd like to cite Nicholas Georgescu Roegen (1987), a pioneer of environmental economics:

"Any individual must certainly discount the future for the indisputable reason that, being mortal, he stands a chance of dying any day. But a nation, let alone the whole of mankind, cannot behave on the idea that it might die tomorrow. They behave as if they were immortal and, hence, value future welfare situations without discounting."

3. Member States use much lower discount rates than recent EC Impact Assessments.

There is wide evidence from practical applications in EU Member States' impact assessments for using much lower discount rates for determining energy system costs as currently applied in EU Impact Assessment. In our analysis we could not find any good reason why there should be major differences in discount rates used in EU Impact Assessments and the average being applied in Member States impact assessments. In fact some Member States explicitly follow the clear advice from earlier EU Impact Assessment Guidelines to use a discount rate of 4%. The most recent example for which discount rates Member States deem to be appropriate is given by their cost-optimality reports. Countries opting for the social perspective on average used a discount rate of

3.3% being very close to the UK rate. Countries opting for a financial perspective applied a discount rate of 5.7%, which we assume to be close to the WACC, the weighted average cost of capital.

4. Discount rates used in EC Impact Assessments for determining the annual total energy system costs should be revised.

In line with the above discussions, preferably an EU wide social discount rate should be calculated based on existing theory. If no consensus can be found about going that way, an average EU WACC could be calculated. Either way we assume the result will be in the range of 3% to max. 6%.

Note that we won't go as far as asking for applying a societal discount rate of 0%. As pointed out in our analysis, there are scientifically sound reasons to apply a certain discount rate to future cash flows without at the same time discounting future *utility* – which probably is what Georgescu Roegen meant. A perfect example is given by the UK's Green Book, which for a time horizon up to 30 years sets a real discount rate of 3.5%, which gradually decreases for the time beyond 30 years.

Lowering the discount rates applied to determining the annual total energy system costs in Commission Impact Assessments also would be a way forward to solve the contradictory recommendations in the new Better Regulation Guidelines about when to use a societal perspective and when to use "economy wide modelling". Still we'd like to repeat, that we do not see the option to interpret "economy wide modelling" as doing calculations of total energy system costs with "subjective" discount rates, as those exist for the single purpose of simulating individual decision making.

5. The translation of barriers and policy measures into "subjective" discount rates needs to be transparent.

In PRIMES, the "subjective discount rate" applied in stage 1 of the calculation is the major parameter mimicking individual decision making about technology choices. This of course is also true for the default set of discount rates used as an input for calculating the PRIMES reference scenario: note that already the reference scenario of course implies consideration of a certain set of barriers and the implementation of a certain set of existing policies. This is important as obviously these decisions determine the structure of the energy system.
In discussions we had and in literature we encountered the strong and logical view that ambitious, consistent and persistent energy efficiency (or renewable energy) policies will and must significantly reduce subjective discount rates (cf. e.g. [Dupuy, 2015]).
At the same time evidence from our literature review also suggests that significant research is needed to better understand the actual impact of policies on individual technology choices.[24] Yet, for exactly this lack of a common understanding, as-transparent-as-possible explanations for the rationale for policy-driven adaptations of subjective discount rates should accompany every impact

[24] A way forward might be to further analyse the MURE EE database, containing approx. 2,000 end-use measures. This might help to calibrate savings effects of measures.

assessment. So far we couldn't find *concrete satisfactory* explanations in EU Impact Assessment related documents e.g. for the declining subjective discount rates for households due to the impact of the EED (see Table 1).
As a starting point for achieving more transparency, we could imagine a matrix like the one presented in Table 3, explaining which policy responses to the barriers covered by subjective discount rates are part of a certain policy scenario and which reduction of the subjective discount rate is attributed to each policy response. The ultimate goal should be to have mathematical functions describing the decline of discount rates as a response to policy measures.

6. The role of Impact Assessments is to support and not to replace policy making. PRIMES inputs, logic and outputs should be fully transparent. Outputs should always be tested against other modelling tools.

The former Impact Assessment Guidelines clearly defined Impact Assessments as a support but not as a replacement of policy making. This is also true for the underlying modelling. Modelling must be useful to support policy makers in their decisions [Bataille et al., 2006]. *A pre-condition is that policy makers can understand what is going on in the modelling.*
Recently several authors have asked for more transparency and stressed the need to consistently apply sensitivity analysis in EU Impact Assessments, e.g. [Smit et al., 2014], [Hedenus et al., 2013], [Knopf et al., 2015] and [Renda et al., 2013]. We fully support this sentiment. In [Smit et al., 2014] it turned out that e.g. a full explanation of different PRIMES results (e.g. 2020 values from 2007 and 2013 reference scenario) from published documentation is impossible.
The same goes for our own understanding about what is happening in PRIMES modelling. For all we know from the available documentation we have good reasons to assume that changing the discount rate has a very significant impact on the outcome. Yet, we also noted that payback periods (or even other factors) might potentially compensate for discount rate impacts; due to lack of unambiguous documentation we don't know.
Because of this we can safely assume that policy makers are not fully aware of the reasons for changes in modelling results either. But policy makers should have sufficient information on how the modelling works and which parameters have the most significant influence – because they are the ones who need to consciously decide about certain input parameters for the model runs, and they are also the ones who need to interpret the results for proper policy making.

From our own development of complex computer models we are aware that it is quite some effort to sufficiently describe every relevant model feature. Yet, the least that needs to be done in projects with overarching public interest is to openly list all input parameters and reasons for why they have been chosen. Therefore we strongly recommend to strive for utmost transparency in order to avoid a "black box" impression which spoils confidence in modelling, its inputs and outcomes, which again spoils confidence in subsequent decisions about EU energy and climate policy and thus Europe's future.

Due to the importance of understanding the impact of energy and climate policies on the energy system and the European economy and the complexity of the underlying modelling, we recommend to *always* verify PRIMES scenarios with results from other modelling tools. In chapter 4.5.1 we pointed out that e.g. other models produced significantly more positive results for the EU economy from strong energy efficiency policy than the PRIMES scenarios. Reasons for such differences must be understood and if need be, algorithms or inputs need to be adapted in one or the other model.

In discussions, we have heard that PRIMES is a legacy and should not be changed too much in order to keep the ability to reproduce former results and maintain continuity. We are convinced that such an approach will undermine the value of and trust in PRIMES' modelling results.

It is imperative that over time, current modelling tools evolve in order to reflect the rapid changes in the energy system we are witnessing today. More and more sectors are becoming interlinked, individuals play a more and more important role in the overall energy system. This is fully acknowledged in the [JRC, 2014] publication "Towards an Integrated Roadmap" which says: "There is hence a pressing need for a robust and transparent analytical framework that provides policy makers with extensive interdisciplinary knowledge and allows them to assess the linkages, synergies, and disconnects between energy technologies and services, infrastructure, markets, business creation and consumer behaviour." "Interdisciplinary analysis needs to understand how to move away from the technologies, infrastructures and interests that constitute legacy energy systems." "The definition of policies supporting the energy transition requires improved methods and tools to assess the social, political, economic and environmental dimension of energy systems, considering costs and benefits for consumers and for society as a whole."

Returning to the introduction to this paper, [IEA, 2014] highlights that we need significant research to better understand the dynamics and outcomes of energy and climate policies, to improve measurement of multiple benefits, and to improve the evidence base to support policy making.

Therefore we would like to conclude by citing [Pfenninger et al., 2014], and stating that "we always need to keep aware whether current methods are appropriate for 21st century problems; do not let gain established methods get primacy just because of their familiarity." Under any circumstances we need "to avoid the trap of modelling what is easily quantifiable rather than what really matters."

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7 Annexes

7.1 Annex I: The impact of the discount rates on annuities and the attractiveness of alternative energy efficiency investments

Two alternative energy efficiency investments are compared applying three different discount rates. Table 4 summarizes the relevant financial parameters.
Table 4 clearly shows that annual energy system costs increase with increasing discount rates due to increasing annuities for the investment. Furthermore the high efficiency alternative is preferable (due to lower system costs) at 0% and 4%, but not anymore at 17.5% - the default PRIMES discount rate – as now its advantage in energy cost is overcompensated by the difference of its annuity compared to the low efficiency alternative.

Table 4. Financial parameters of two alternative energy efficiency investments

	High Efficiency	Low Efficiency
Investment today	1000 €	800€
Annual energy cost	110 €	140 €
Energy price increase	0%	
Discount rate 1	0% (no discounting, nominal cash flow)	
Discount rate 2	4% (real rate, i.e. adjusted for inflation)	
Discount rate 3	17.5% (real rate, i.e. adjusted for inflation)	
Lifetime	20 years	

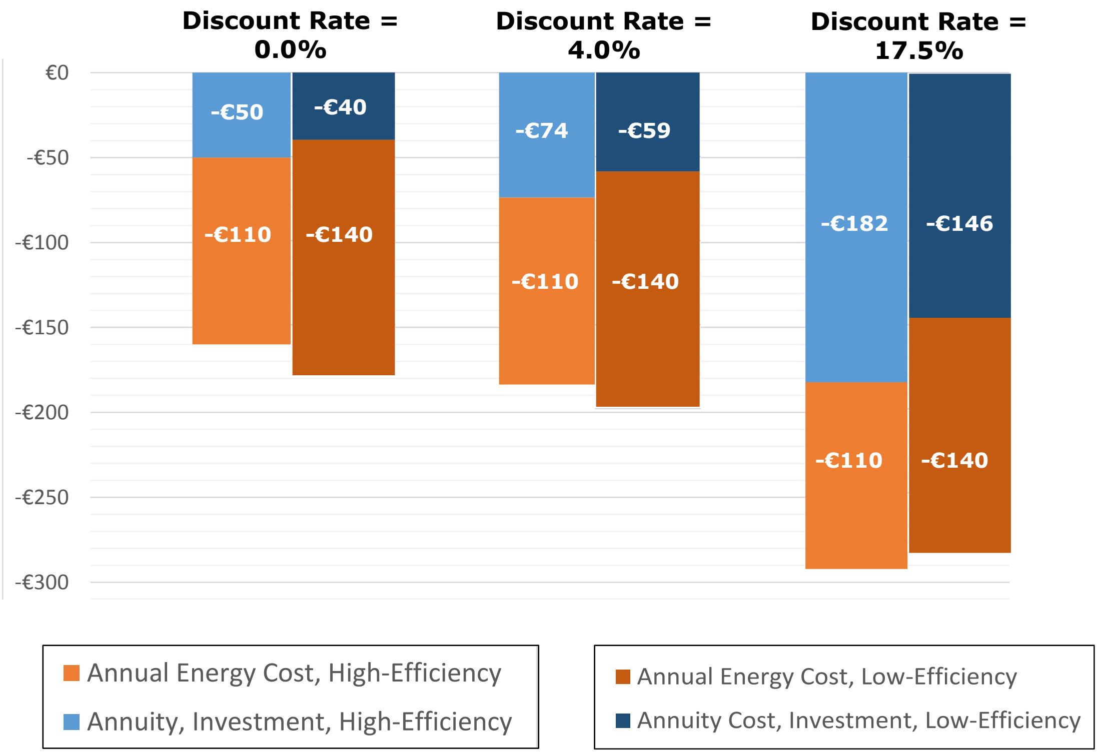

Figure 3. Annual energy system cost resulting from different discount rates

7.2 Annex II: The impact of the discount rate on global cost and subsequent decisions about alternative energy efficiency investments

The same alternatives as presented in Annex I are presented here, in Annex II. The net present value of cash flows is calculated for both alternatives applying three different discount rates. The preferable alternative is the one having the smaller (i.e. "less negative") amount of the net present value. For 0% and 4% this is the high efficiency alternative, for 17.5% this is the low efficiency alternative. Here the reason is that future advantages in energy cost lose more weight in the net present value the higher the discount rate. Therefore the higher the discount rate the more dominant the differences in upfront investment become for the investment decision.

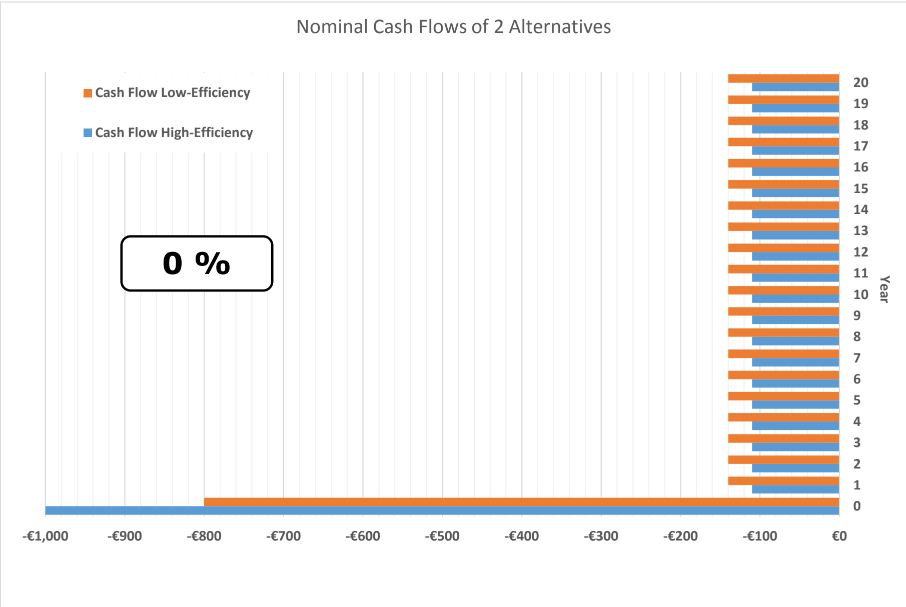

Figure 4. Visualisation of example: nominal cash flows of alternatives 1 & 2; identical values result in case of calculating the present values of these nominal cash flows applying a discount rate (DR) = 0%

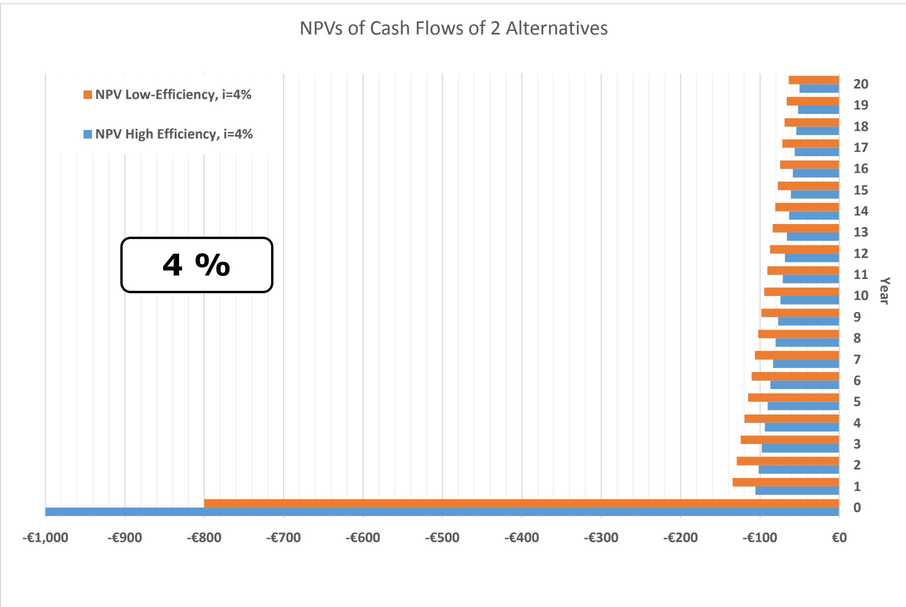

Figure 5. Visualisation of example: present values of discounted cash flows of alternatives 1 & 2 applying DR = 4%

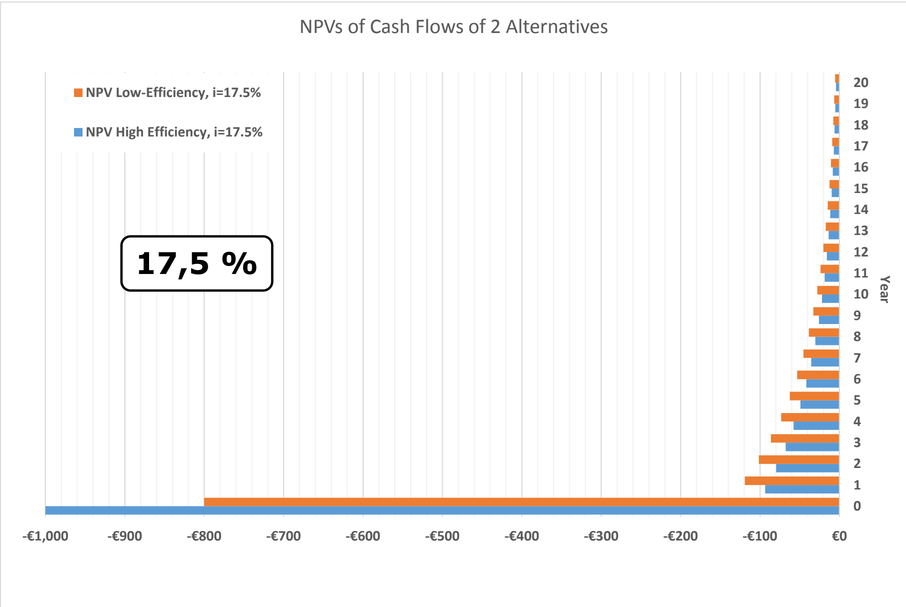

Figure 6. Visualisation of example: present values of discounted cash flows of alternatives 1 & 2 applying DR = 17.5%

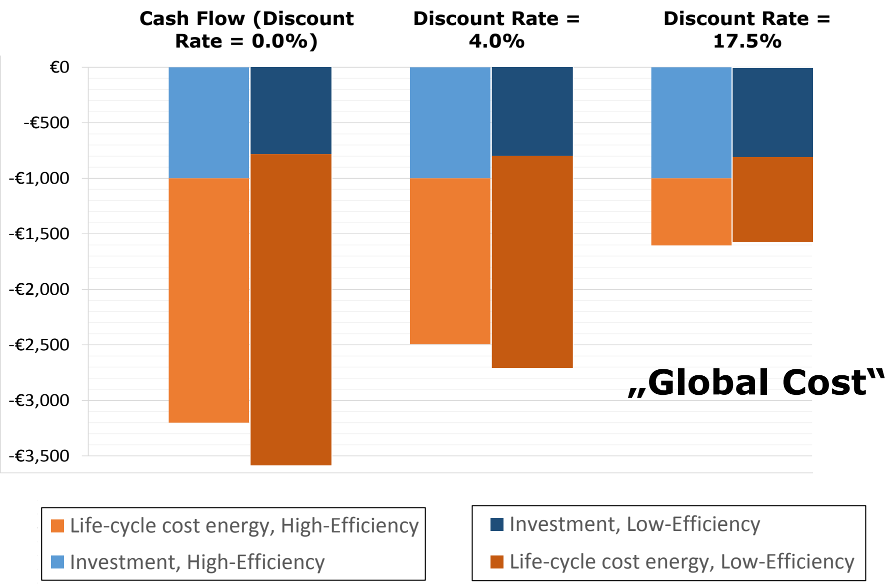

Figure 7. Comparison of sum of present values of discounted cash flows (= net present value (NPV)) in case of the applied discount rate being 0%, 4% or 17.5%.

While the high-efficiency investment is preferable in the cases of a 0% or 4% discount rate, the low-efficiency alternative is preferable when applying a discount rate of 17.5%. In the latter case the advantage of the lower NPV of the life-cycle cost for energy (sum of present values of annual energy cost) does not overcompensate anymore the additional initial investment cost which remains unaffected by the discount rate in the NPV calculation.

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