Endogenous energy efficiency improvement of large-scale retrofit in the Swiss residential building stock

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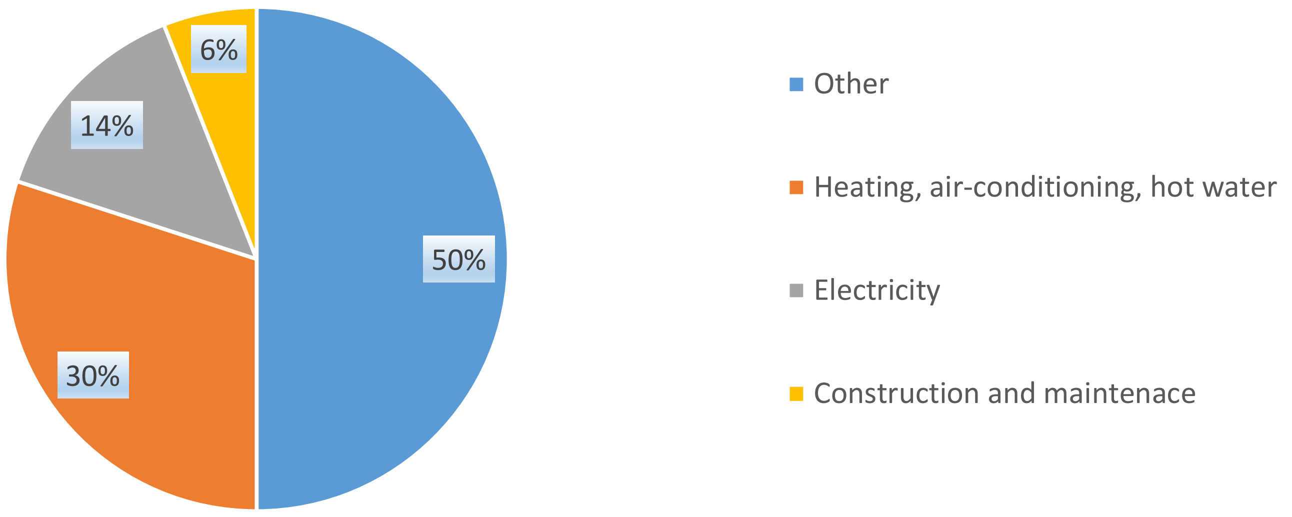
Introduction

According to SFOE: 50 % of energy consumption in Switzerland is attributable to buildings:

- The evolution of energy efficiency (EE) takes an important role for energy consumption



- In the literature in the field of Swiss energy and climate policies, the expansion of EE improvement is set exogenously
- It is considered to be unaffected by energy policies for innovation and the development
- It is important because making endogeneous EE improvement will probably help to more efficient energy policies

Objectives

Introduce a new methodology in an existing economic model of the Swiss economy targeting at a better representation of the acceleration of EEI due to energy and climate policies

↓

Illustrate this by assessing the impacts of a set of realistic policies on the adoption of technologies associated with energy consumption in Switzerland

Policy relevance

The model will allow addressing the following policy relevant key questions:

How effective are current and planned energy and climate policies in stimulating EEI?

What are the impacts of these policies on energy imports and use, on the energy mix and on CO_2 emissions?

How can existing models (CGE models) be improved efficiently to generate more realistic scenario results?

How can existing and planned policies be made effective in promoting EEI? What new instruments could be helpful?

Academic value added

The main academic added values are the following:

a) To demonstrate a theoretically founded and computationally tractable integration of endogenous technical change (ETC) due to policy into a macroeconomic simulation model

b) To show how relevant ETC can be integrated in energy and climate policy simulation

Review of theoretical foundations

- One reason why most economic models applied to energy policy content with exogenous EEI: the introduction of endogeneity is difficult to generalize to several sectors and to several countries.

- The lack of statistical database at a worldwide level is an important limitation

- **CONTRARY:** My project focuses on one country (Switzerland) and two representative sectors: *housing* and an *industry sector*

- Good availability of data will increase considerably its feasibility

Housing

A decomposition of the buildings stock of Switzerland that is relevant for its energy consumption is needed.

Distinguishing by:

Building age (construction period)

Specific energy efficiency indicators (CECB classification) (Gebäudeenergieausweis der Kantone)

Energy carrier* (heating oil, natural gas, district heating, electricity, etc)

Formal model done

The housing stock is grouped into energy cohorts EC that will follow CECB (Cantonal Energy Certificate for Buildings) classification. The classification is given in Table 1

Each energy cohort has fixed specific space heating demand and the energy cohorts are ranked with the following relationship:

$$SHD_{A,t} < SHD_{B,t} < \ldots < SHD_{F,t} < SHD_{G,t} \quad \forall t$$

I need to combine my the model with GEMINI-E3* so that I will be able to perform policy simulations

GEMINI-E3 is a computable general equilibrium (CGE) model that was specifically designed to assess energy and climate change policies

Formal model done

The quantity of buildings in cohort: measured by the total energy reference area ERA (m^2) in the cohort

The ERA changes from one period to the next through:

a) Demolition

b) New construction

c) Transfers between cohorts (refurbishment) *

*A cohort loses buildings whose energy efficiency is improved to a better EC label.

*It gains buildings from less efficient cohorts that get improved to its own EC label.

Table 1 CECB labels

	Efficiency of the building envelope	Overall energy efficiency
A	Excellent thermal insulation with triple- glazed windows.	State-of-the art technical installations in the building for the production of heat (heating and domestic hot water) and light; use of renewable energies.
B	New building achieved a B , rating according to the legislation in force.	Standard for new buildings and technical installations; use of renewable energies.
C	Older properties where the building envelope has been completely renovated.	Older properties that have been completely renovated (building envelope and technical installations), most often using renewable energies.
D	A building that has been satisfactory and completely insulated retrospectively, but with some thermal bridges remaining.	The building has been renovated to a large extent but presents some obvious shortcomings, or does not use renewable energies.
E	A building with significantly improved thermal insulation, including the installation of new insulating glazing.	A partially renovated building, with a new heat generator and possibly new appliances and lighting.
F	A partially insulated building.	A building partially renovated at best, with replacement of some equipment or use of renewable energies.
G	A non-renovated building with retro - fitted insulation that is incomplete or defective at best,and having exten - sive potential for renovation.	A non-renovated building with no use of, renewable energies and with extensive potential for renovation.

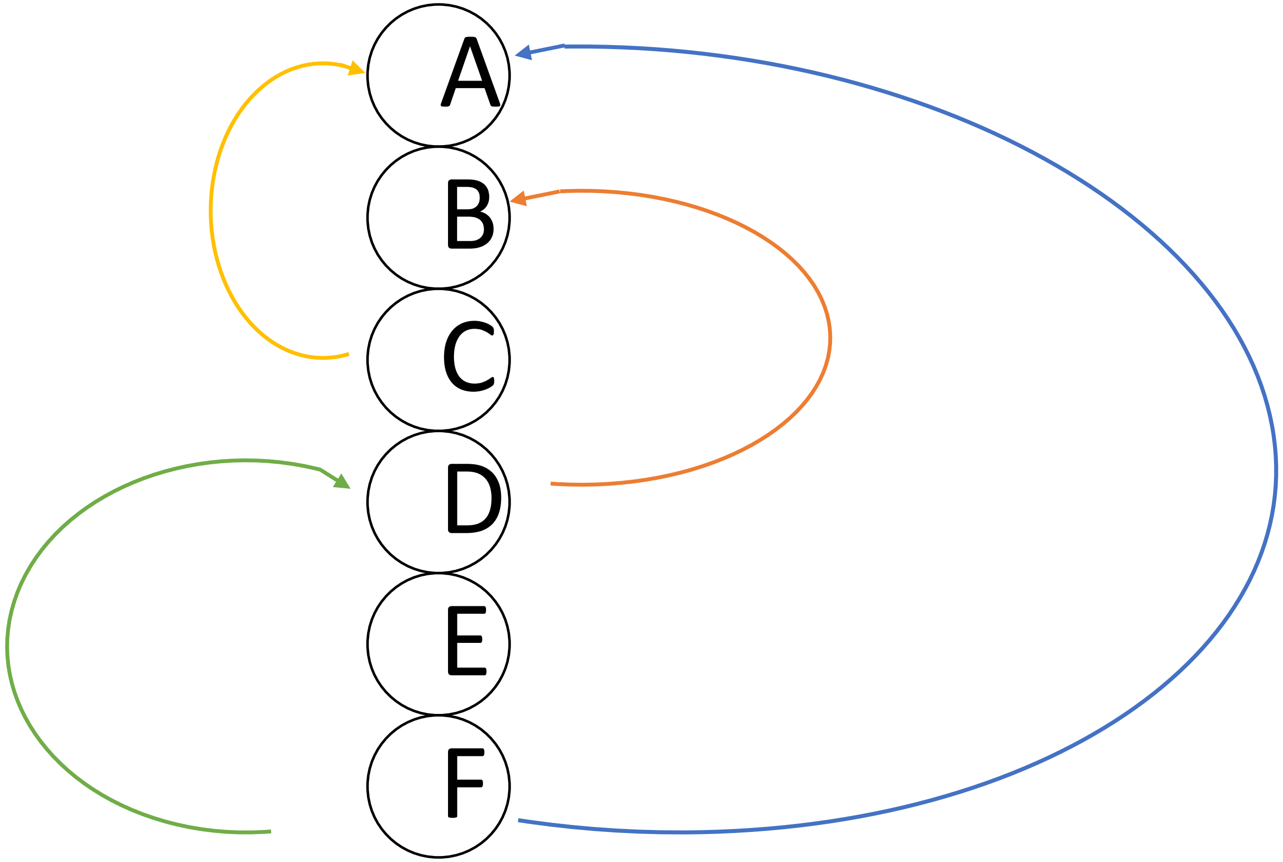
$$ERA_{EC}^{CP,OT,t+1} = (1 - DR^{CP,t}) \cdot ERA_{EC}^{CP,OT,t} + NC_{EC}^{CP,OT,t} - \sum_{A}^{EC'<EC} RM_{EC,EC'}^{CP,OT,t} + \sum_{EC'>EC}^{G} RM_{EC',EC}^{CP,OT,t}$$

Refurbishment behavior

- The energy consumption of the building stock changes when buildings are refurbished and when the heating system is replaced

- Refurbishment moves buildings from one cohort to a higher cohort

- The better the energy refurbishment, the higher cohort the building moves to, i.e. it becomes equivalent to a more recent building



Housing

Refurbishment decision depends on:

1) First layer: pure economic costs, that is (i) investment costs and (ii) retrofit benefits in form of saved energy costs
2) Second layer: further individual characteristics of the buildings and owner, such as:

age of the building	*building type (single and multi-family houses)*
owner type	*location*
type and age of heating system	*owner preferences, risk attitudes*

Housing

Owner type characteristics:

Group OT	Owner type	Characteristics	Share of owner type	Discount rate r	Split incentive parameter χ
1	owner - occupied	young and wealthy	8%	2%	1
2	owner - occupied	other	24%	4%	1
3	owner - occupied	old and/or poor	8%	6%	1
4	landlord	cooperative & municipalities	6%	2%	0.5
5	landlord	investment corporations & pension funds	18%	4%	0.5
6	landlord	households	36%	6%	0.5

Split incentives is a barrier to the implementation of energy efficiency measures in buildings. It arises when those responsible for paying energy bills, (the tenant), are not the same who make capital investment decisions (landlord).

The decision of retrofit

1) First step: Probability of being triggered

In the first step, the owner of the house is triggered (for example: by receiving a letter from the community, speaking with his/her spouse) and orders an energy audit.

The probability is an increasing function of the information level (Inf:{1;2;3;4})

2) Second step: Decision on retrofit

Depending on the result of the energy audit, he decides on doing the retrofit or not.

We have also defined four different property owner types that have different discount rates.

Database collection:

I need data in order to calibrate the model

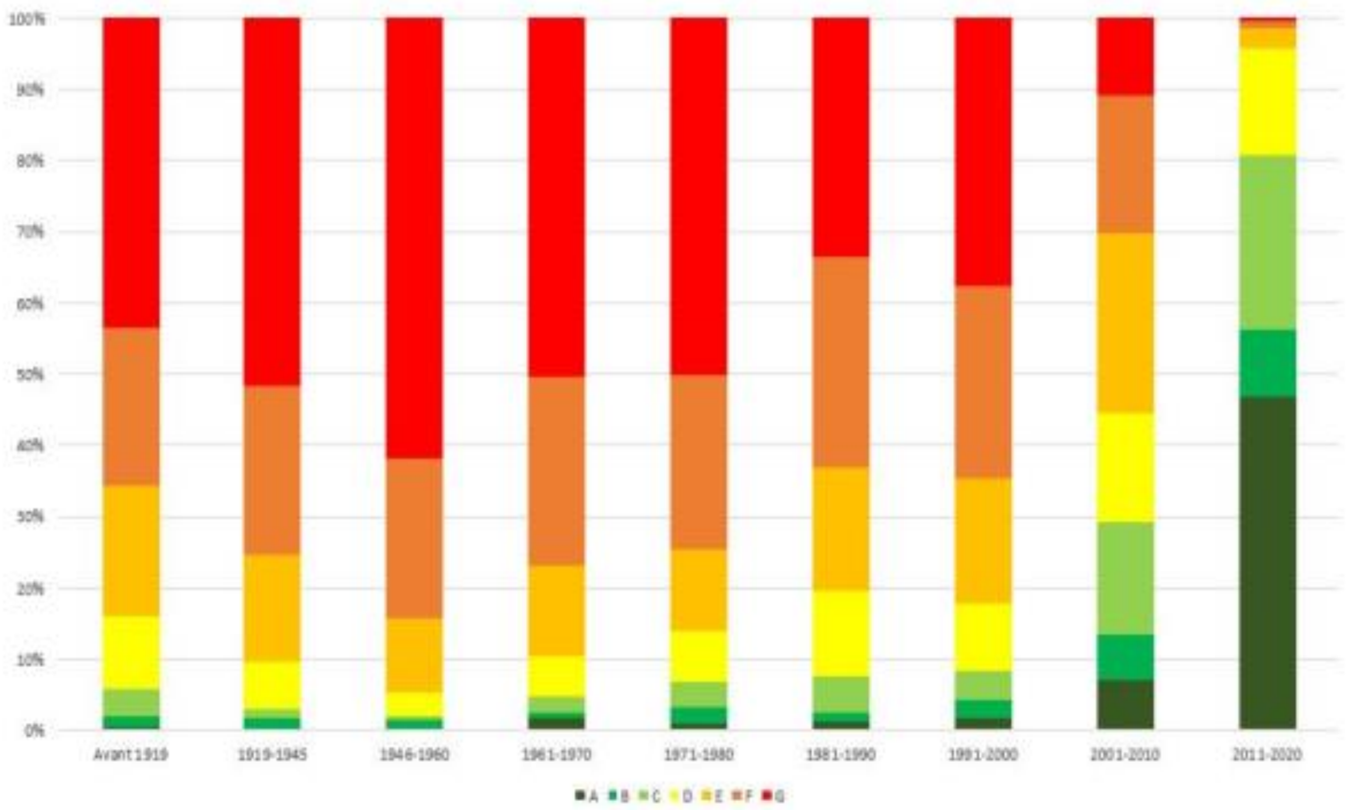
Parameter	Unit	Source
Annual Increase in housing	number	SFOE
Occupied Housing	number	SFOE
New constructions	number	SFOE
Average surface per year and per number of rooms	square meter	SFOE
Degree-days of heating	degree	SFOE
Average surface per inhabitant	number	SFOE
Population	number	SFOE
Buildings by canton, building category, heating system, hot water production, energy agent and time of construction	number	SFOE
Energy Reference Area (ERA)	square meter	SFOE
Buildings by type of heating, energetic agents used for heating and cantons	number	SFOE
Distribution of buildings according to the energy agents of heating and hot water	percentage	SFOE
Distribution of buildings by heating system	percentage	SFOE
Dwellings by type of heating, energetic agents used for heating, by age of construction and renovation	number	SFOE
Buildings by territorial division, by type of heating and energetic agents used for heating	number	SFOE

Parameter	Unit	Source
Average Space Heating Demand per ERA and year of construction of Single and Multi family houses (Useful and Final energy)	kWh / m^2	Martin Patel (UNIGE)
Share of total Swiss Space Heating Demand per year	percentage	Martin Patel (UNIGE)
Energy Reference Area (ERA)	square meter	SCEER
Average surface per cohort	square meter	Our estimations
Demolition rate	percentage	Our estimations
New constructions per capita	number	Our estimations
New constructions' overall surface	square meter	Our estimations
Energy consumption of Single and Multi Family houses by energy carrier	Joule	Our estimations
Refurbishment Cost	CHF / m^2	Our estimations
Space heating demand	kWh / m^2	Our estimations
Energy consumption per square meter for Canton of Zurich	kWh / m^2	Energie in Wohnbauten (AWEL, Zurich, 2014)

Data Collected

City	Source	Number of dwellings	Year taken	Energy
Lausanne	SCHL	2 011(app.)	2016/2017	Heating
Zürich	ABZ	4 540 (app.)	2016/2017	Heating + Hot water
Geneva	ESTIA	17 983 (app. + buildings)	2015	Heating + Hot water
Different cities	Mobiliar	236 (buildings)	2015	Heating

Distribution of ERA: three cities and die Mobiliar



Results

5 main Scenarios were conducted:

- ❑Reference scenario
- ❑Information level scenarios {1,2,3,4}
- ❑Subsidy on retrofit
- ❑Tax on fossil energy (CO2 tax)
- ❑Combining economic instruments

Results

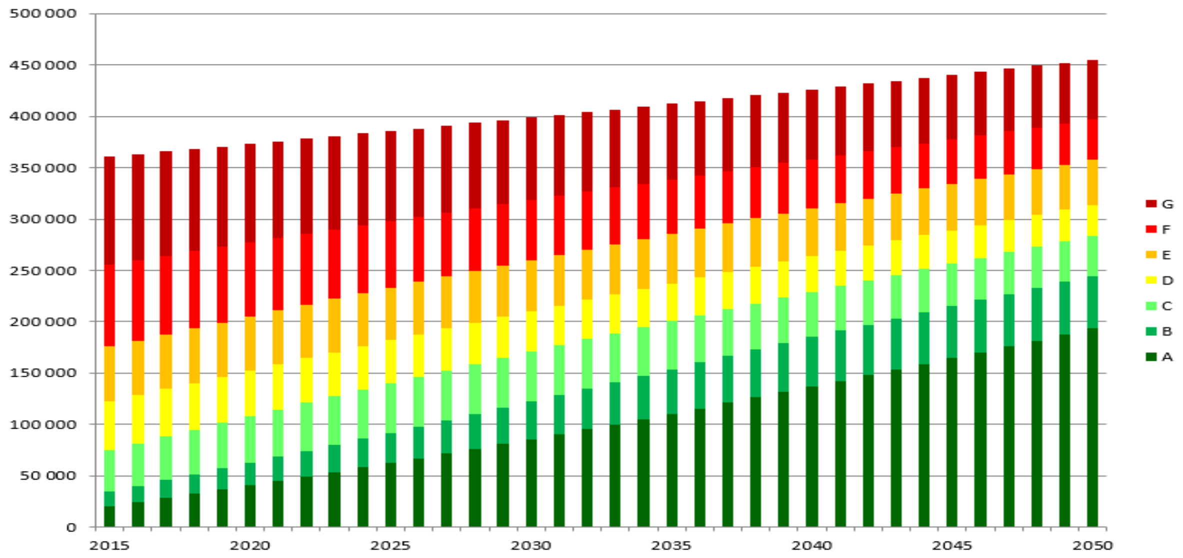
Reference Scenario

We assume six property owner types, with the respective discount rates, 2%, 4%, 6%, 2%, 4%, 6%

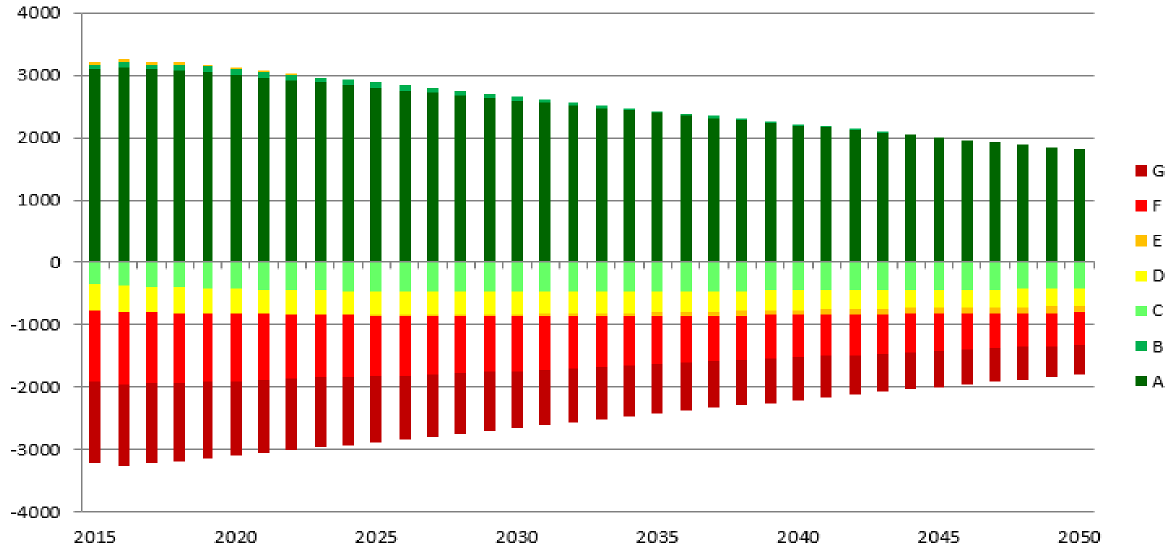
Buildings are mainly retrofitted in energy class A and to a lesser extent in class E.

The retrofitted energy classes are G, F, D, C and B.

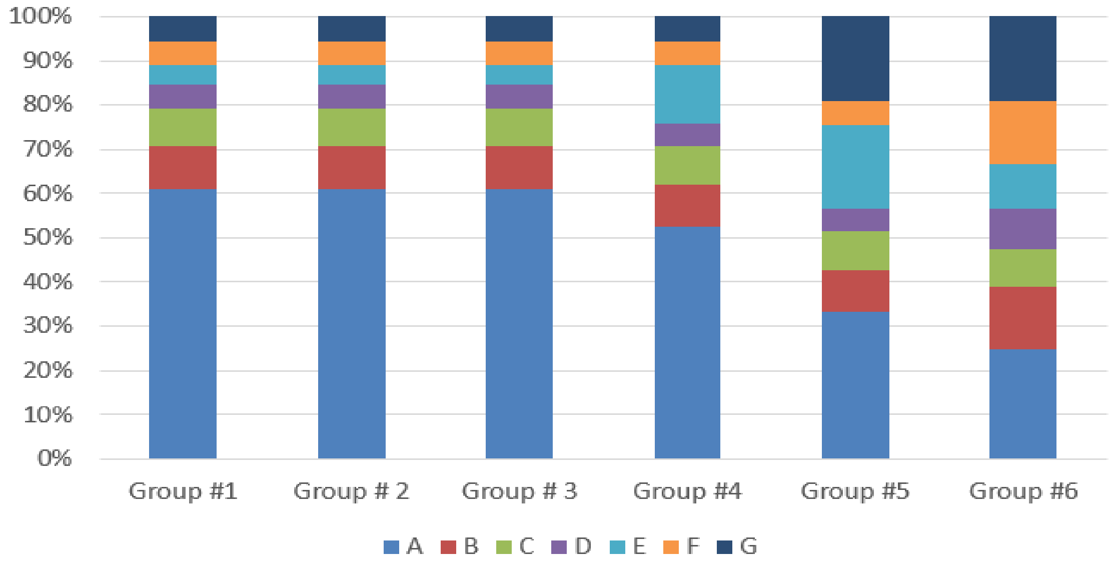
As it can be seen in the first Figure, that the surface of energy class E is slightly increasing.



Energy reference area in sqm - Reference scenario



Retrofit in sqm - Reference scenario (negative numbers are buildings that are subtracted, positive numbers are buildings that are added to an energy class)



Energy reference area in % per energy classes by owner groups - Reference scenario

Results

Information level scenarios

Increasing the information level augments the probability of doing an audit but does not change the economic profitability of the retrofit decision.

With the information level 4, the average energy consumption reaches 50 kWh/m2 and CO_2 emissions decrease by 65% with respect to 2015 levels.

In 2050, energy class A represents 58% of the Swiss building stock, but there are still very inefficient buildings.

Buildings from category G to E account for 23% of the Swiss building stock.

Conclusion: it is necessary to combine information level policy with economic instruments that will affect the economic profitability of the retrofit decision in order to obtain more CO_2 abatements.

EPFL

Information level scenarios

	Reference (Inf=1)	Inf level=2	Inf level=3	Inf level=4
Average retrofit rate	0.75%	1.12%	1.33%	1.46%
Average energy consumption in 2050 in KWh/m	61	54	51	50
CO2 emissions change with respect to 2015	-55%	-61%	-64%	-65%
Share of energy classes in 2050				
A	42%	51%	55%	58%
B	11%	11%	11%	11%
C	9%	6%	4%	3%
D	7%	5%	4%	4%
E	10%	9%	8%	8%
F	9%	6%	6%	5%
G	13%	11%	10%	10%
Average retrofit rate per owner group				
1	1.28%	1.87%	2.17%	2.35%
2	1.28%	1.87%	2.17%	2.35%
3	1.28%	1.87%	2.17%	2.35%
4	1.44%	2.24%	2.69%	2.96%
5	0.61%	0.94%	1.13%	1.26%
6	0.11%	0.20%	0.26%	0.31%
Average energy consumption in 2050 in KWh/m2				
1	43	30	25	23
2	43	30	25	23
3	43	30	25	23
4	49	34	27	24
5	73	70	69	68
6	77	76	76	76
CO2 emissions change with respect to 2015 per owner group				
1	-75%	-88%	-94%	-96%
2	-75%	-88%	-94%	-96%
3	-75%	-88%	-94%	-96%
4	-68%	-83%	-91%	-94%
5	-40%	-43%	-44%	-44%
6	-37%	-37%	-37%	-37%

Results

Subsidy on retrofit scenarios

Subsidy on retrofit for energy classes G and F. Subsidies ranging from 50% to 70%.

If the subsidy increases the retrofit of energy class G, it does not affect the renovation decision for energy class F whose share is almost unchanged within different scenarios.

When the subsidy rate is above 50%, no more retrofit is implemented (i.e. the share of energy class F is unchanged in 2050),

Nevertheless, it affects the energy class in which the retrofit is done (i.e. the share of energy class A is increasing and the shares of energy classes F and G are decreasing).

The subsidy succeeds to increase significantly the CO2 abatement, but again we find that the marginal CO2 abatement is decreasing with the subsidy rate.

If the government decides to subsidize retrofit of buildings that is done from any energy class to the highest energy class A, in these scenarios, per definition, only the share of energy class A is increasing.

Subsidy rate scenarios on energy classes F and G

	Reference (rate=30%)	Subsidy rate=50%	Subsidy rate=60%	Subsidy rate=70%
Average retrofit rate	0.75%	1.07%	1.34%	1.28%
Average energy consumption in 2050 in KWh/m2	61	55	45	43
CO2 emissions change with respect to 2015	-55%	-61%	-72%	-75%
Share of energy classes in 2050				
A	42%	49%	58%	61%
B	11%	10%	10%	10%
C	9%	9%	9%	9%
D	7%	5%	5%	5%
E	10%	11%	8%	4%
F	9%	5%	5%	5%
G	13%	10%	6%	6%
Average retrofit rate per owner group				
1	1.28%	1.28%	1.28%	1.28%
2	1.28%	1.28%	1.28%	1.28%
3	1.28%	1.28%	1.28%	1.28%
4	1.44%	1.28%	1.28%	1.28%
5	0.61%	1.44%	1.28%	1.28%
6	0.11%	0.61%	1.44%	1.28%
Average energy consumption in 2050 in KWh/m2				
1	43	43	43	43
2	43	43	43	43
3	43	43	43	43
4	49	43	43	43
5	73	49	43	43
6	77	73	49	43
CO2 emissions change with respect to 2015 per owner group				
1	-75%	-75%	-75%	-75%
2	-75%	-75%	-75%	-75%
3	-75%	-75%	-75%	-75%
4	-68%	-75%	-75%	-75%
5	-40%	-68%	-75%	-75%
6	-37%	-40%	-68%	-75%

Results

Tax on Fossil energy scenarios

We assume that the government puts a tax on fossil energy ranging from 200 to 1000 CHF per ton of CO_2.

The impact is rather limited in comparison to other economic instruments and does not impact significantly the retrofit decision.

The average energy consumption reaches 37 kWh/m2 and CO_2 emissions decrease by 85% with respect to 2015 levels.

In 2050, energy class A represents 62% of the Swiss building stock, but there are still very inefficient buildings.

Buildings from category G to E account for 15% of the Swiss building stock.

Tax on fossil energy scenario

	Reference (Tax CO2=96)	Taxe CO2=200	Taxe CO2=500	Taxe CO2=1000
Average retrofit rate	0.75%	0.76%	1.16%	1.53%
Average energy consumption in 2050 in KWh/m	61	60	52	37
CO2 emissions change with respect to 2015	-55%	-57%	-68%	-85%
Share of energy classes in 2050				
A	42%	43%	51%	62%
B	11%	11%	10%	14%
C	9%	8%	10%	8%
D	7%	7%	5%	5%
E	10%	9%	10%	3%
F	9%	8%	4%	4%
G	13%	13%	10%	4%
Average retrofit rate per owner group				
1	1.28%	1.32%	1.41%	1.51%
2	1.28%	1.32%	1.41%	1.51%
3	1.28%	1.32%	1.41%	1.51%
4	1.44%	1.32%	1.41%	1.51%
5	0.61%	0.63%	1.51%	1.51%
6	0.11%	0.12%	0.67%	1.58%
Average energy consumption in 2050 in KWh/m2				
1	43	42	39	37
2	43	42	39	37
3	43	42	39	37
4	49	42	39	37
5	73	73	43	37
6	77	77	72	38
CO2 emissions change with respect to 2015 per owner group				
1	-75%	-77%	-81%	-85%
2	-75%	-77%	-81%	-85%
3	-75%	-77%	-81%	-85%
4	-68%	-77%	-81%	-85%
5	-40%	-42%	-79%	-85%
6	-37%	-39%	-46%	-84%

Results

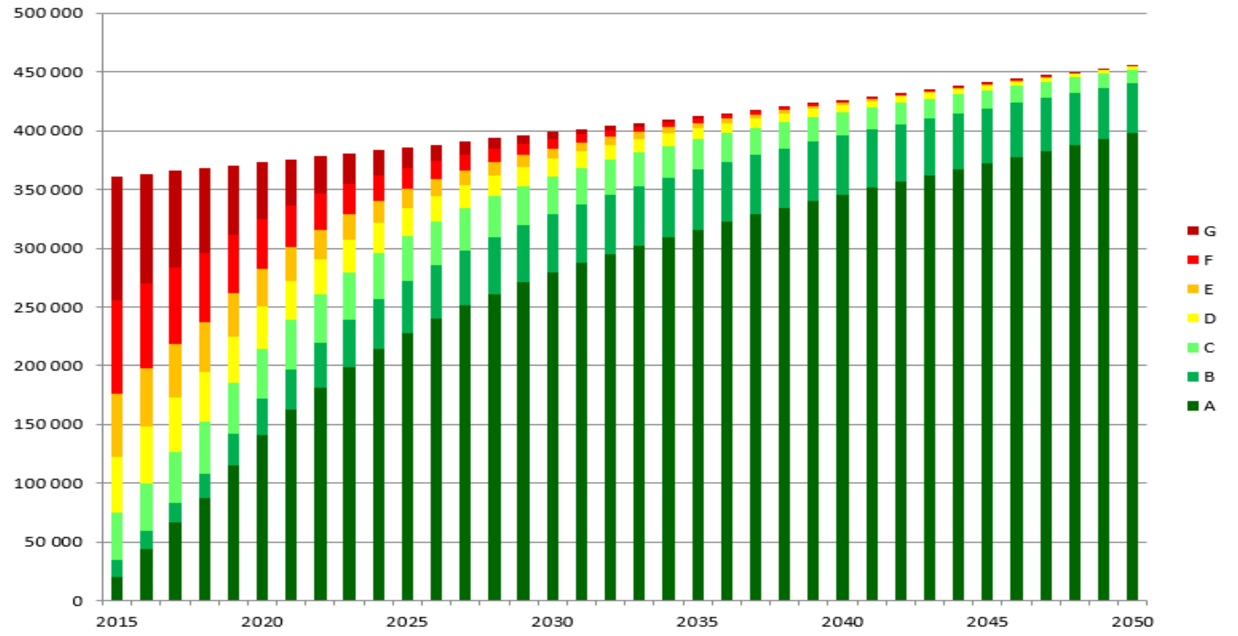
Combining economic instruments

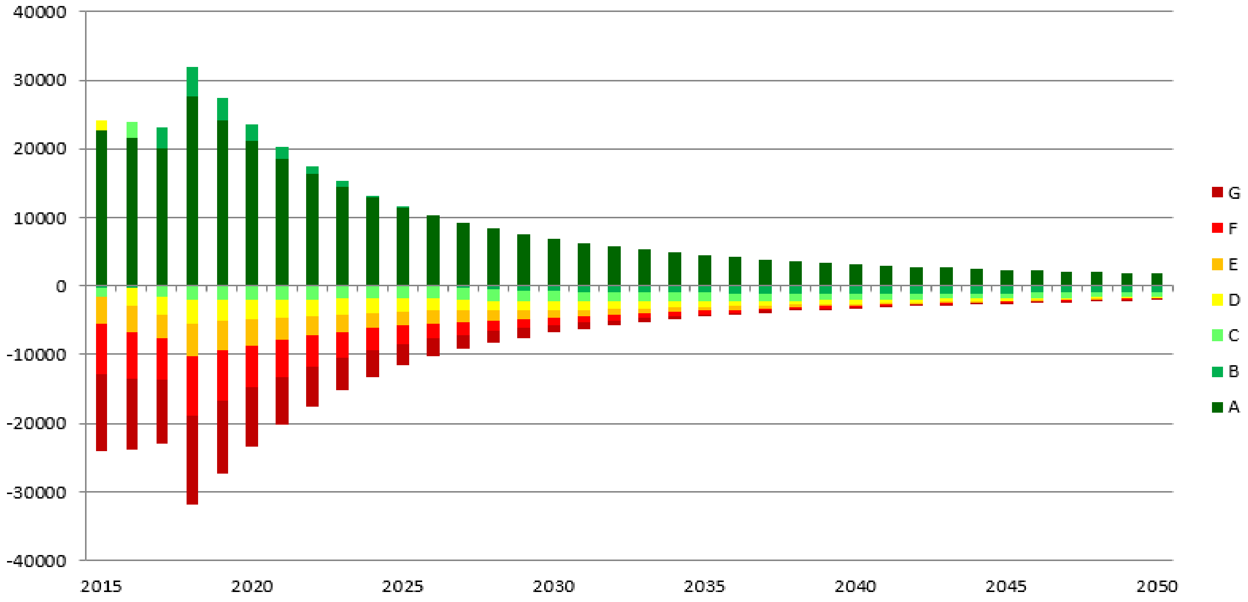
We perform 2 scenarios where we combine all economic instruments:

Scenario A:

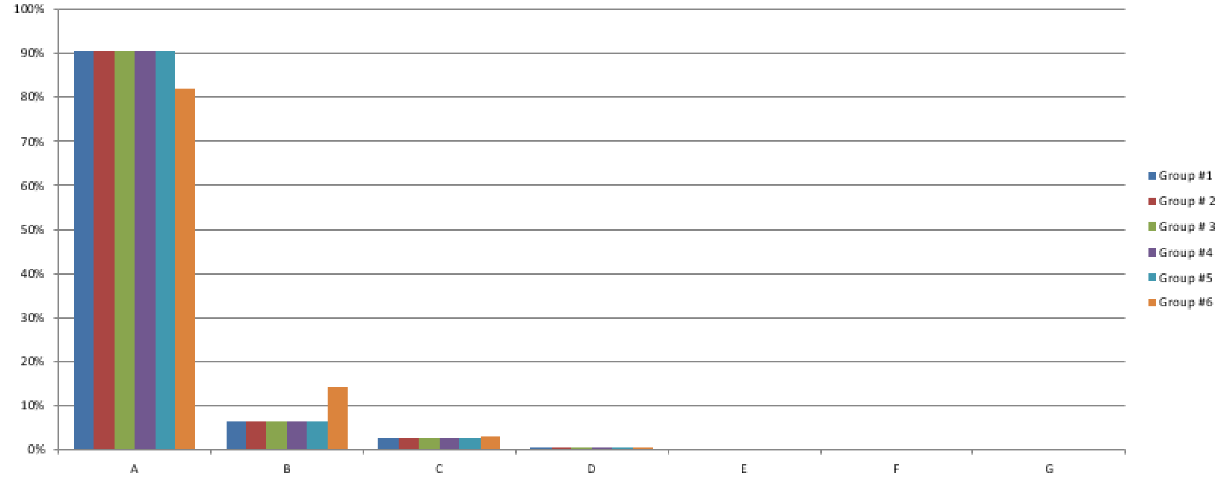
- the information level is equal to 4
- the fossil fuel tax equals 1000 CHF per ton of CO_2

Energy reference area in sqm – Scenario A





Retrofit in sqm – Scenario A (negative numbers are buildings that are subtracted, positive numbers are buildings that are added to an energy class)



Energy reference area in % per energy classes by owner groups - Scenario A

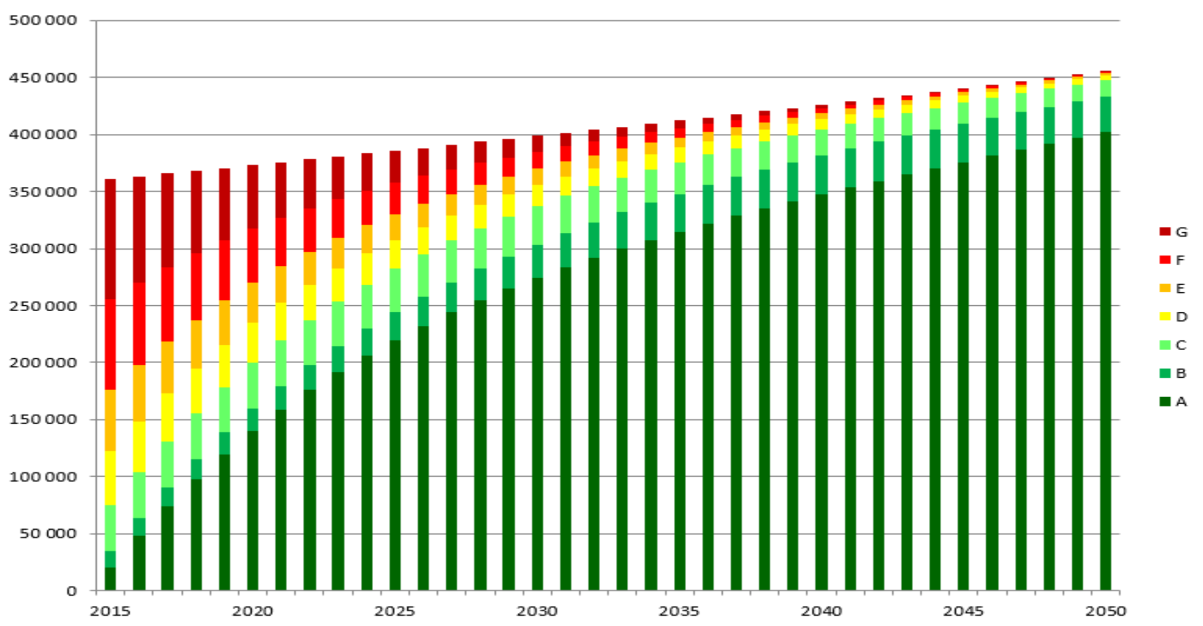
Results

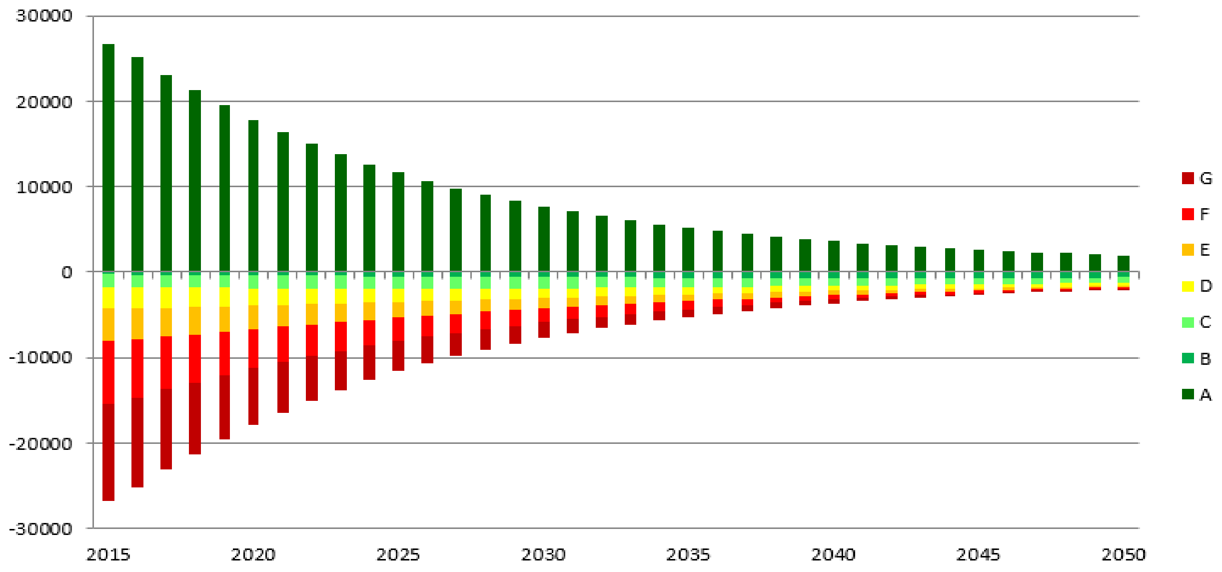
Combining economic instruments

Scenario B:

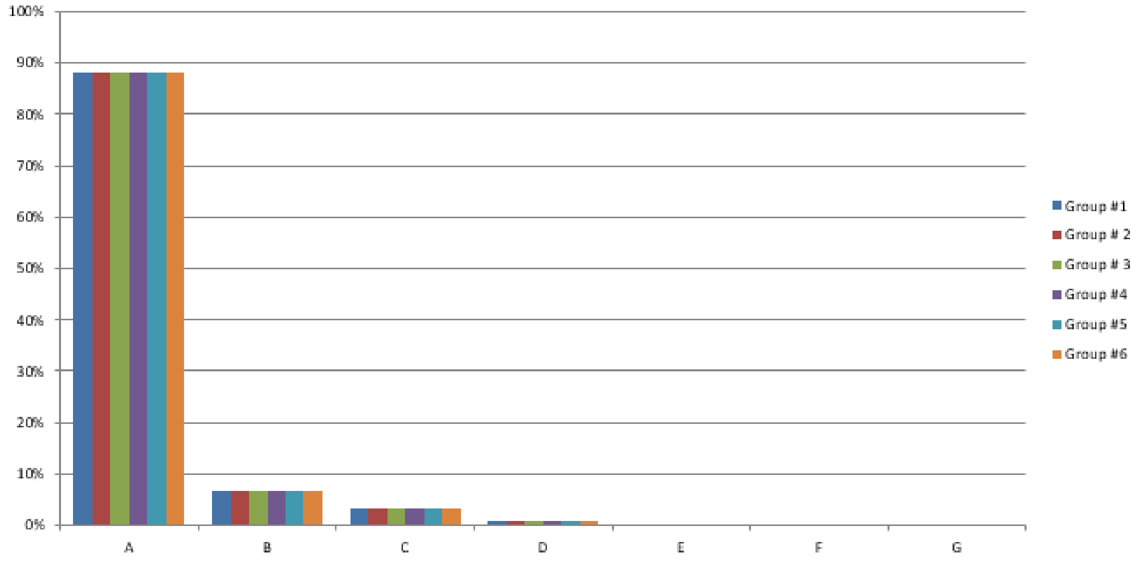
- the information level is equal to 4
- subsidy on retrofit equals 70%

Energy reference area in sqm – Scenario B





Retrofit in sqm – Scenario B (negative numbers are buildings that are subtracted, positive numbers are buildings that are added to an energy class)



Energy reference area in % per energy classes by owner groups - Scenario B

Conclusions

1. Without new government policies, CO_2 emissions decrease by 42% with respect to the current level
2. Group #5 and #6 do not implement retrofit investment due to lack of economic incentive, i.e. the ***refurbishment cost is too high***
3. Increasing information level does not significantly change the behavior of group #5 and #6

4. High CO_2 taxes give incentives to group # 5 and #6 but do not change other groups
5. Same results for subsidy rates on refurbishment cost
6. If we combined information level with subsidy or CO_2 tax we can achieve a ***deep decarbonization pathway***

Further improvements

Housing

EPFL

The validity of the model will be tested:

Through its ability to replicate the observed heating energy use of buildings

Several simple energy and climate policies, aimed at the housing sector will be simulated (with GEMINI-E3, including the effects of barriers)*

Integration of barriers into the model

A prudent representation will considerably effect rigorousness of a policy which is indispensable*

Barriers arise from incomplete information, uncertainty, bounded rationality, market failures.

The following steps will be undertaken to integrate barriers:

Find and improve suitable input data parameters / equations / structures in GEMINI-E3 to model barriers.

Housing

We have two options how to include individual characteristics into the investment decision:

Version Histograms:

Construction of histograms of benefits/costs within an energy cohort (which finally determines the investment decision)

Version Discrete Choice:

The pure economic costs (first layer) and maybe some characteristics of the second layer will be used as input to a discrete choice model

Now it is not clear which approach is best suited for the respective barriers in the respective sectors.

It will depend on data availability and the complexity of an approach in comparison to the expected model improvements.