

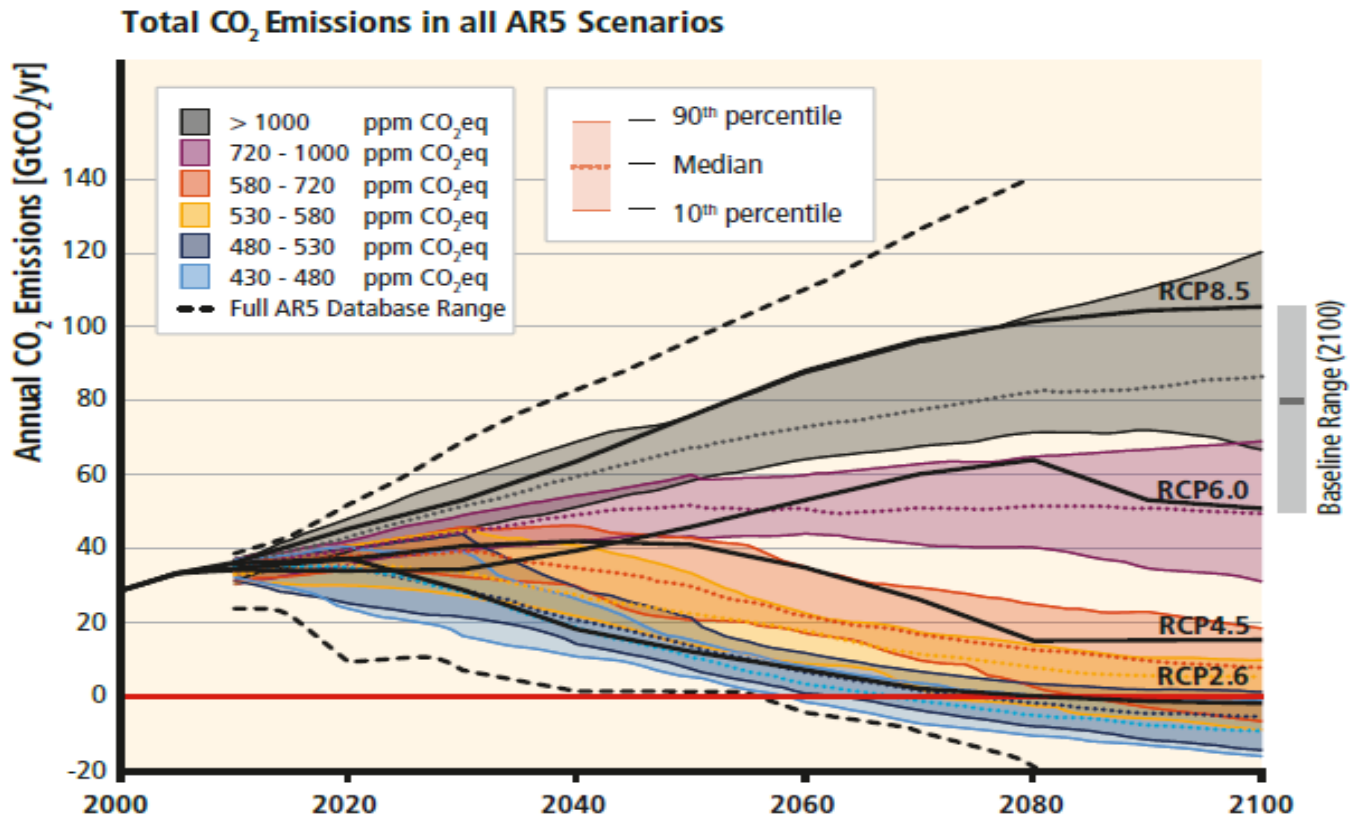
# CARBON NEUTRALITY CHALLENGES FOR FRANCE IN 2072

Ariane Millot, Rémy Doudard, Thomas Le Gallic, Edi Assoumou, François Briens, Nadia Maïzi

Mines ParisTech, PSL Research University, Centre for Applied Mathematics

# WHY A CARBON NEUTRALITY GOAL?

- 2015 : Paris Agreement  
 → target: "well below 2°C"



Source : IPCC Report AR5

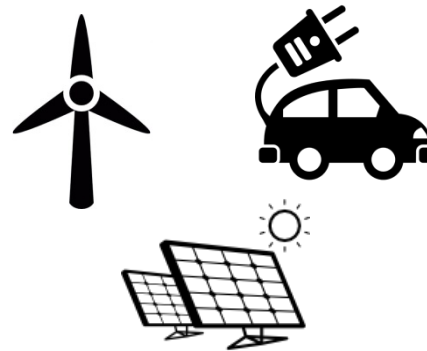
# A MULTIDIMENSIONAL APPROACH

- Target of 1.5°C for global warming : on what levers can we act on ?

Lifestyle



Technologies



Economy



- What impact of lifestyles changes on CO2 emissions pathways?

**Proposal of an approach to associate these dimensions**



# METHODOLOGY

## COMBINATION OF PROSPECTIVE MODELLING



# HOW CAN WE COMBINE THE 3 ASPECTS?

$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$

$$\times \left( \sum_{i \in TCH} fixom_i(t) \right)$$

$$+ \sum_{i \in EEA} \sum_{z \in Z} \sum_{y \in Y} var$$

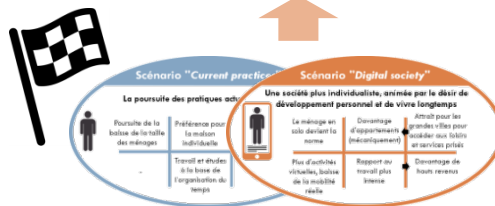
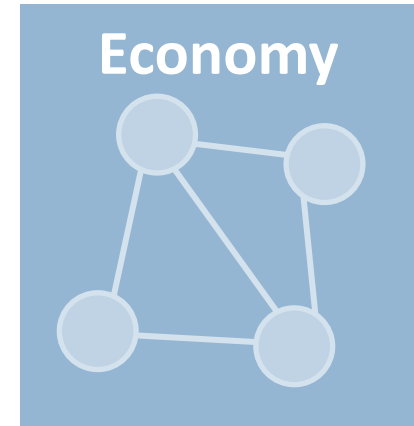
$$+ \sum_{k \in ENC} \sum_s cos$$

$$+ \sum_s \sum_{z \in Z} \sum_{y \in Y}$$

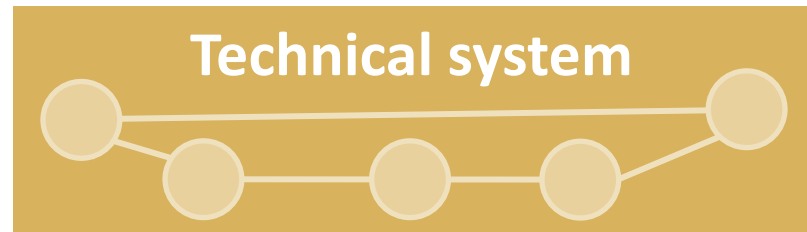
$$- \sum_s \sum_{z \in Z} \sum_{y \in Y}$$



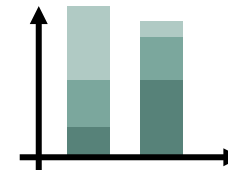
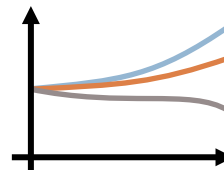
**Demand**



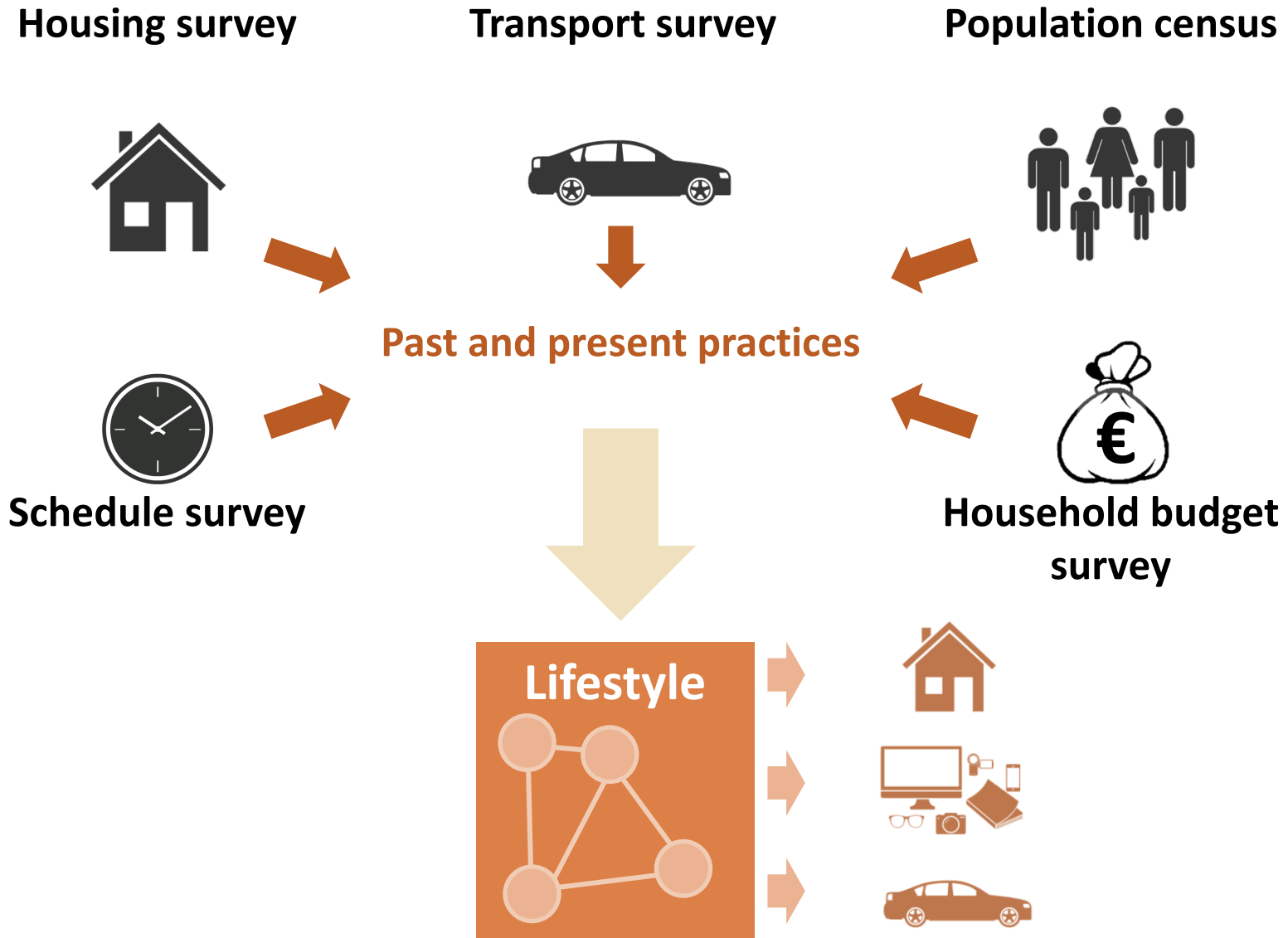
**Volume of activity**



**Energy mix, GHG emissions, final energy consumption**



# A MODEL FOR THE POPULATION AND THEIR LIFESTYLES



# INPUT-OUTPUT ANALYSIS

	Industry	Transport	Services	Final demand	Total = Production
Industry	10	20	50	20	100
Transport	10	10	20	40	80
Services	20	20	10	20	70

*Intermediary production for each sector (IC)*
*Production for the final demand (D)*

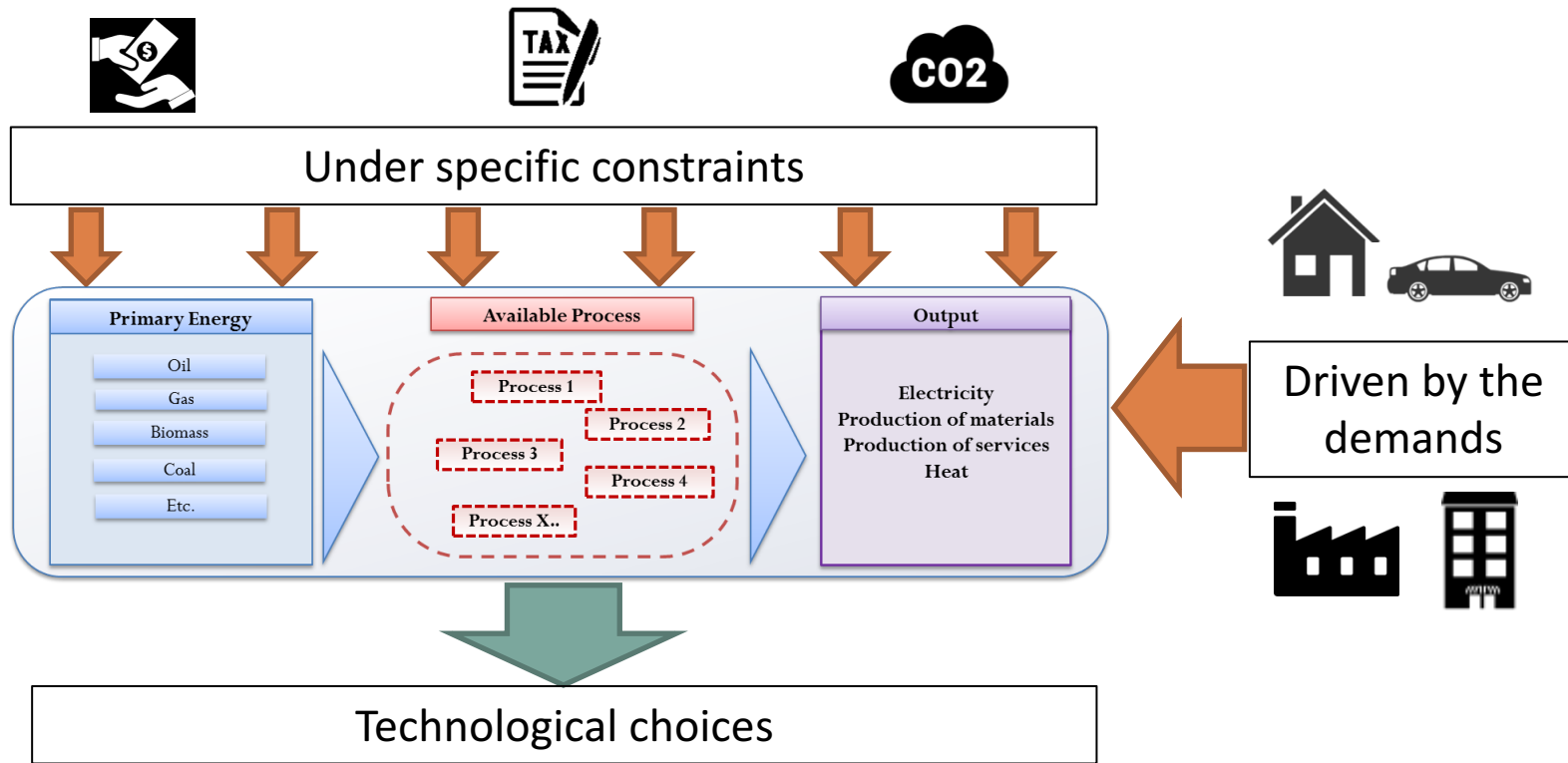
Production (P) = Intermediary consumption (IC) + Final Demand (D)

We introduce A the matrix of technical coefficients such as  $IC = A * P$  and we have :

$$P = A * P + D \quad \text{ie} \quad P = (I - A)^{-1} D$$

→ Production of each sector in function of the demand and the matrix of technical coefficient (Leontieff matrix)

# TIMES-FR : A BOTTOM-UP OPTIMIZATION MODEL FOR THE ENERGY SYSTEM



Goal : Minimize the overall discounted cost of the energy system in France (2014-2072)

$$\sum_{\substack{y \in \text{years} \\ \text{regions}}} \text{Disc}(y) \times (\text{INVCOST}(y) + \text{FIXCOST}(y) + \text{VARCOST}(y) + \text{TAXSUB}(y) + \text{COSTDECOM}(y) + \text{ELASTCOST}(y) - \text{LATEREVENUES}(y)) - \text{SALVAGE} = \text{OBJ}(y)$$

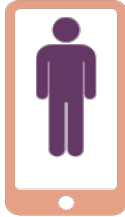




**WHAT IMPACTS OF LIFESTYLES?**

# TWO CONTRASTED LIFESTYLES

## Digital society



**A more individualistic technological and digital society, focused on self-development:**

- Long life expectancy
- A lot of household of 1 person
- More flats
- More virtual activities and leisures
- Large cities and the town centers are attractive
- Work at the heart of the organization (increase of the proportion of high-income households)

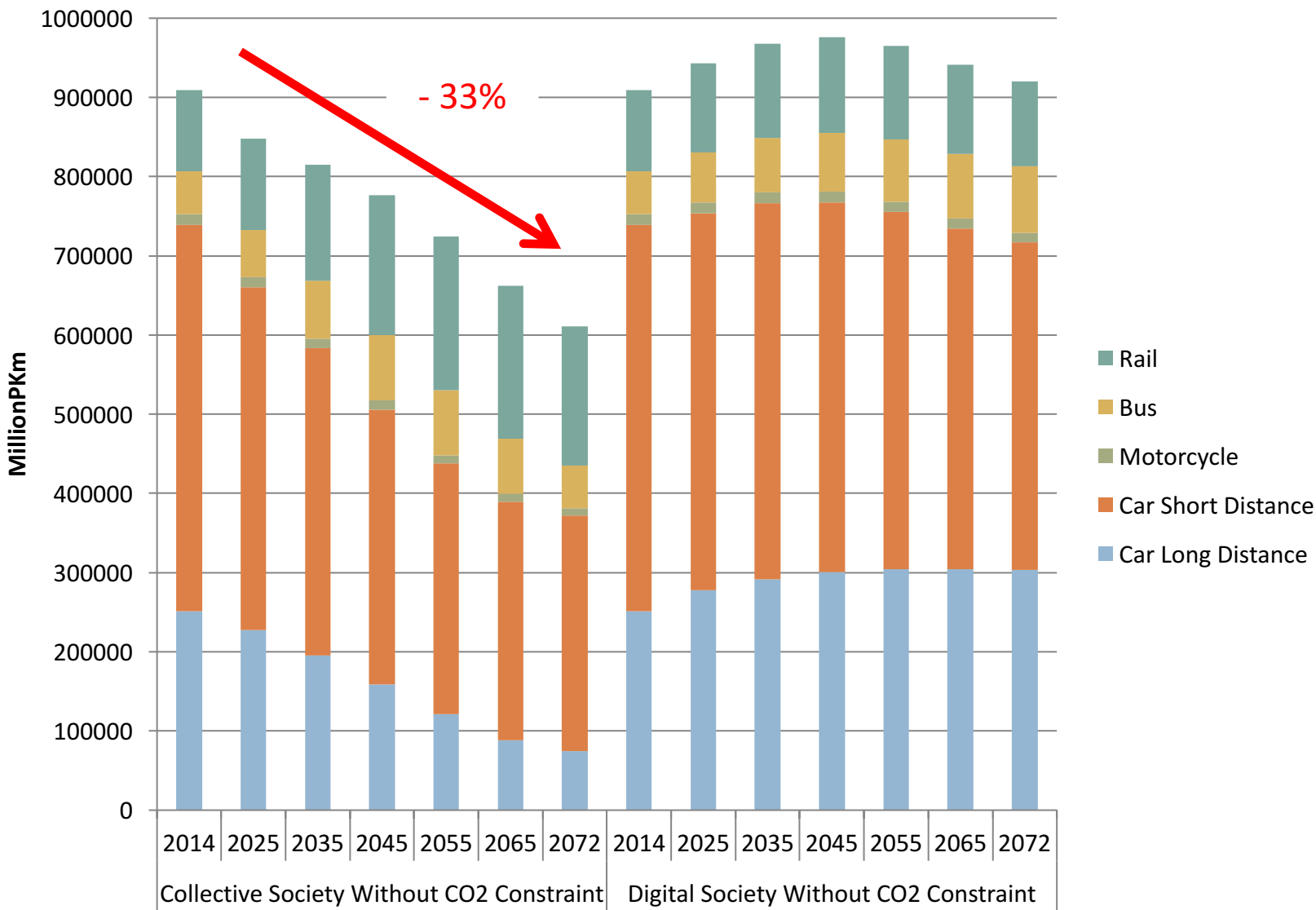
## Collective society

**Social ties and cooperation are placed at the heart of the society and its organization:**

- Group housing
- Activities at the quarter level
- Urban and rural areas popular in contrary of periurban
- Development of coworking spaces
- Share of work (fewer unemployed people)



# WHAT INFLUENCE OF LIFESTYLES ON DEMAND IN THE TRANSPORT SECTOR?



# WHAT CONSEQUENCE ON TIMES OUTPUT : THE FINAL ENERGY CONSUMPTION

$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$

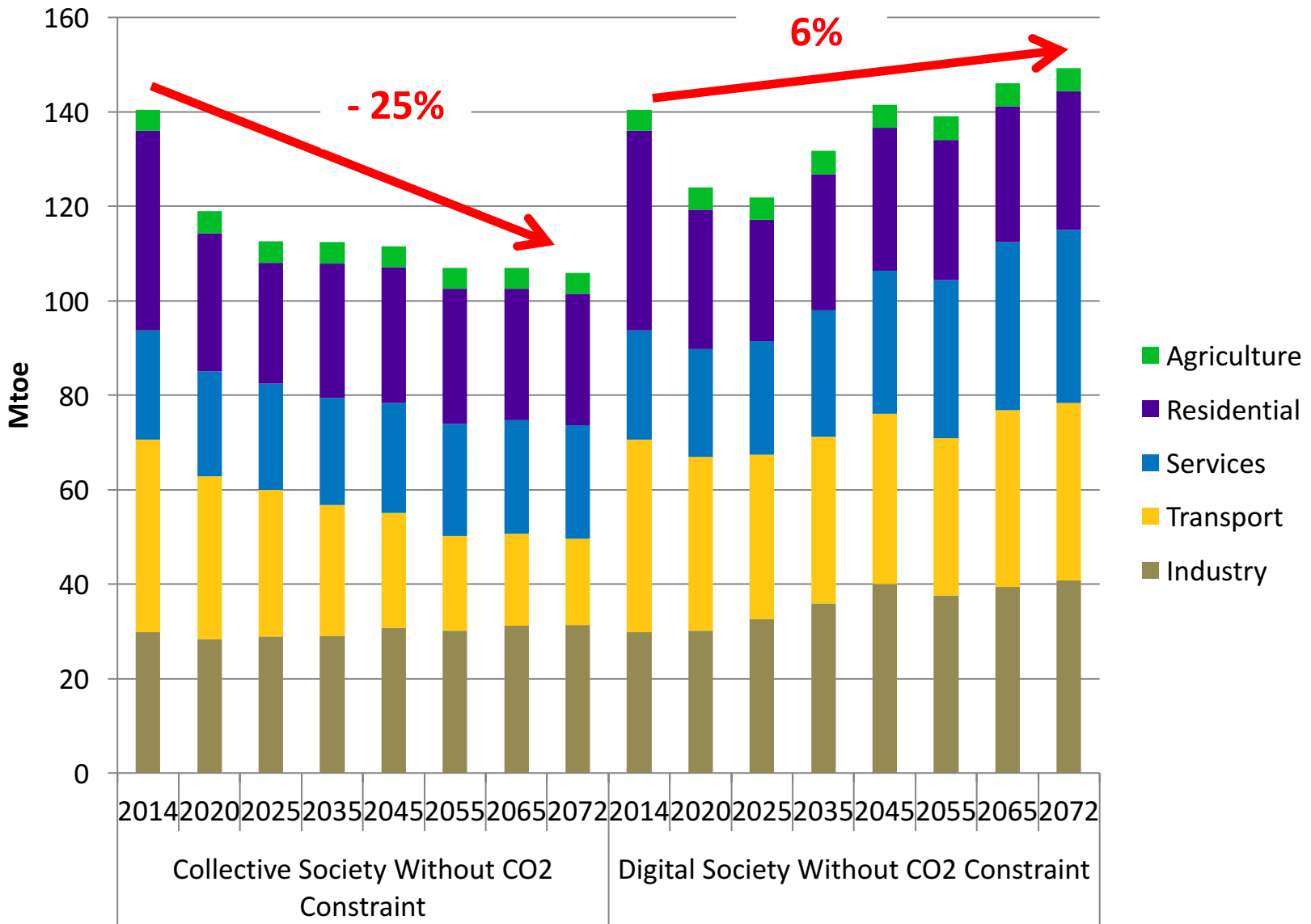
$$\times \left( \sum_{i \in TCH} fixom_i(t) \right)$$

$$+ \sum_{i \in EELA} \sum_{z \in Z} \sum_{y \in Y} varc$$

$$+ \sum_{k \in ENC} \sum_s cos$$

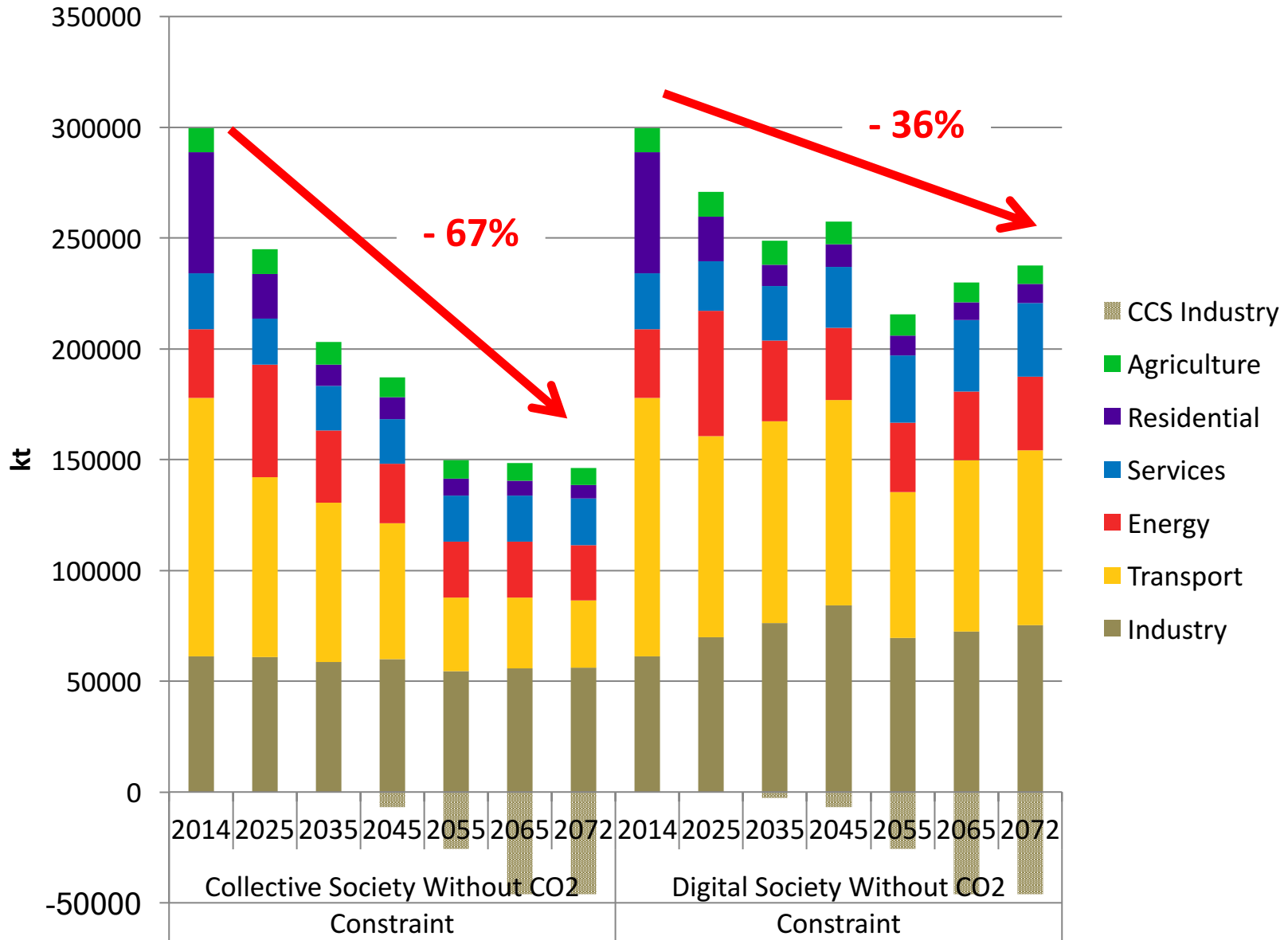
$$+ \sum_s \sum_{z \in Z} \sum_{y \in Y}$$

$$- \sum_s \sum_{z \in Z} \sum_{y \in Y}$$





# WHAT CONSEQUENCE ON TIMES OUTPUT : THE CO2 EMISSIONS





# WHAT IMPACTS OF A CARBON NEUTRALITY GOAL?

# CARBON NEUTRALITY IN 2072

$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$
$$\times \left( \sum_{i \in TCH} fixom_i(t) \right)$$
$$+ \sum_{i \in ELLA} \sum_{z \in Z} \sum_{y \in Y} varo$$
$$+ \sum_{k \in ENC} \sum_s cos$$
$$+ \sum_s \sum_{z \in Z} \sum_{y \in Y} price$$
$$- \sum_s \sum_{z \in Z} \sum_{y \in Y} price$$

2030 : - 40% GHG vs 1990



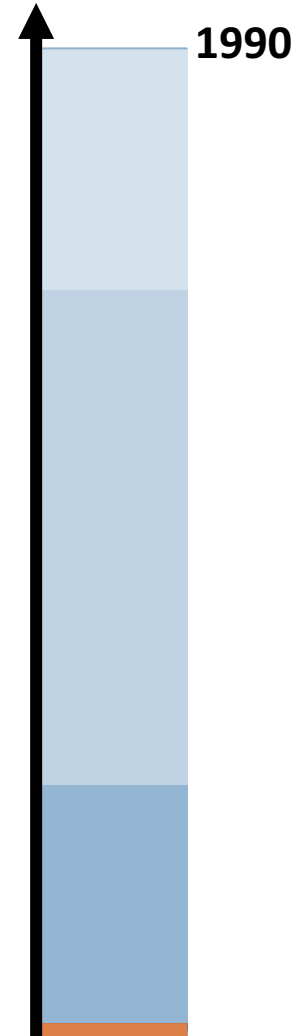
CURRENT COMMITMENT



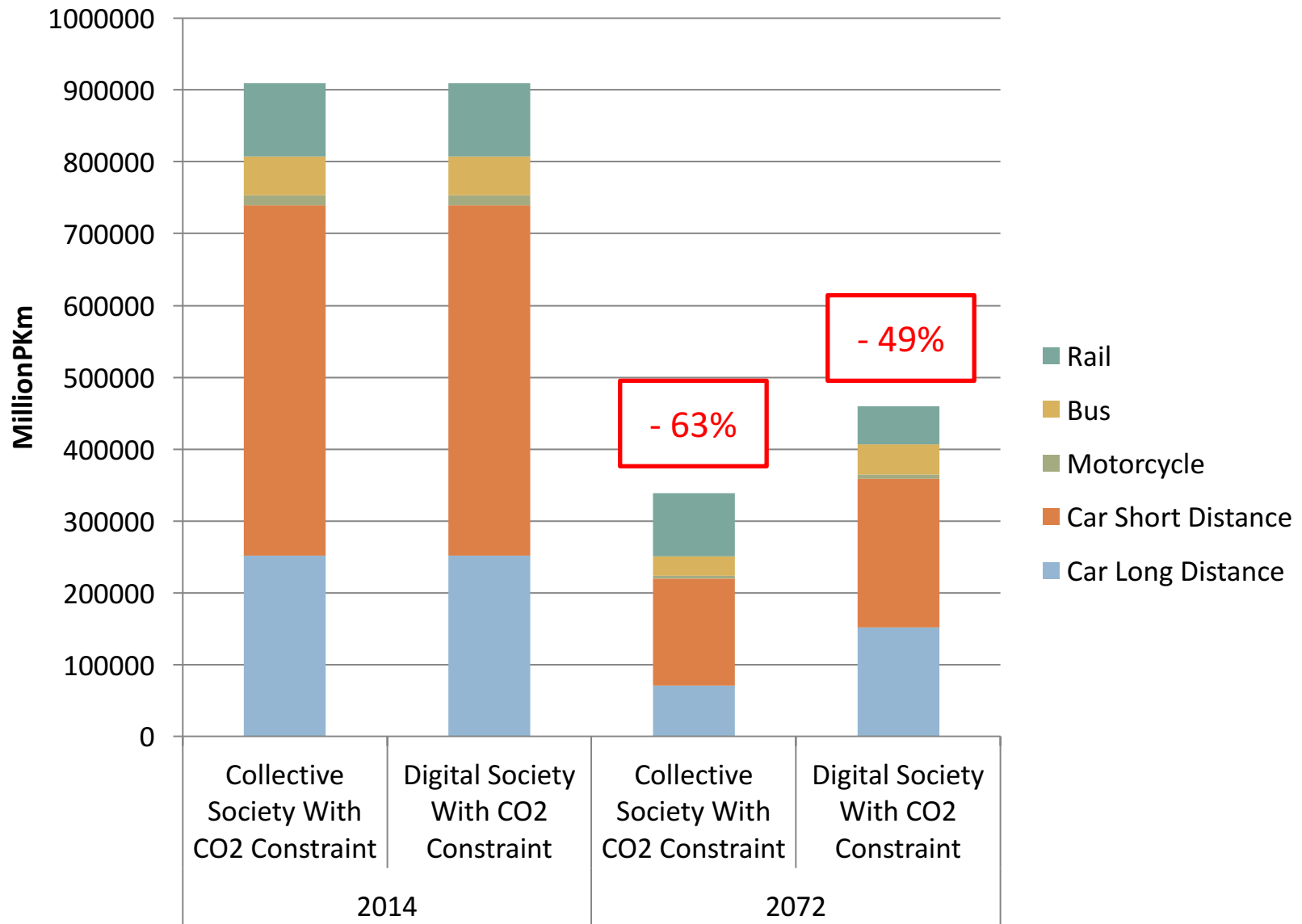
2050 : - 75% GHG vs 1990

FUTURE COMMITMENT (HYPOTHESIS)

2072 : 0 GHG



# ELASTICITY REDUCES THE DEMAND IN THE TRANSPORT SECTOR BY...





# THE CO2 CONSTRAINT REDUCES THE FINAL ENERGY CONSUMPTION BY...

$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$

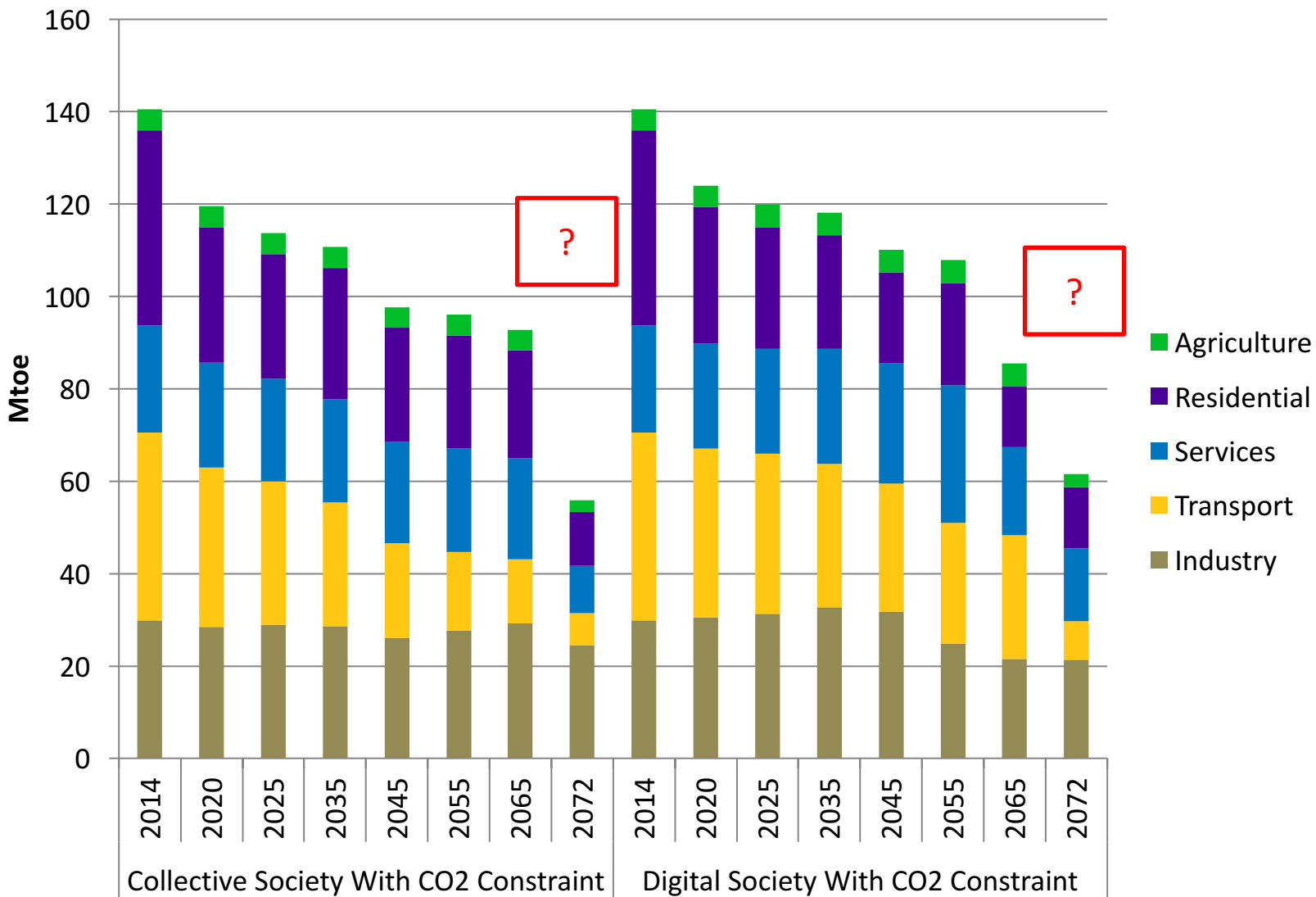
$$\times \left( \sum_{i \in TCH} fixom_i(t) \right)$$

$$+ \sum_{i \in EELA} \sum_{z \in Z} \sum_{y \in Y} varc$$

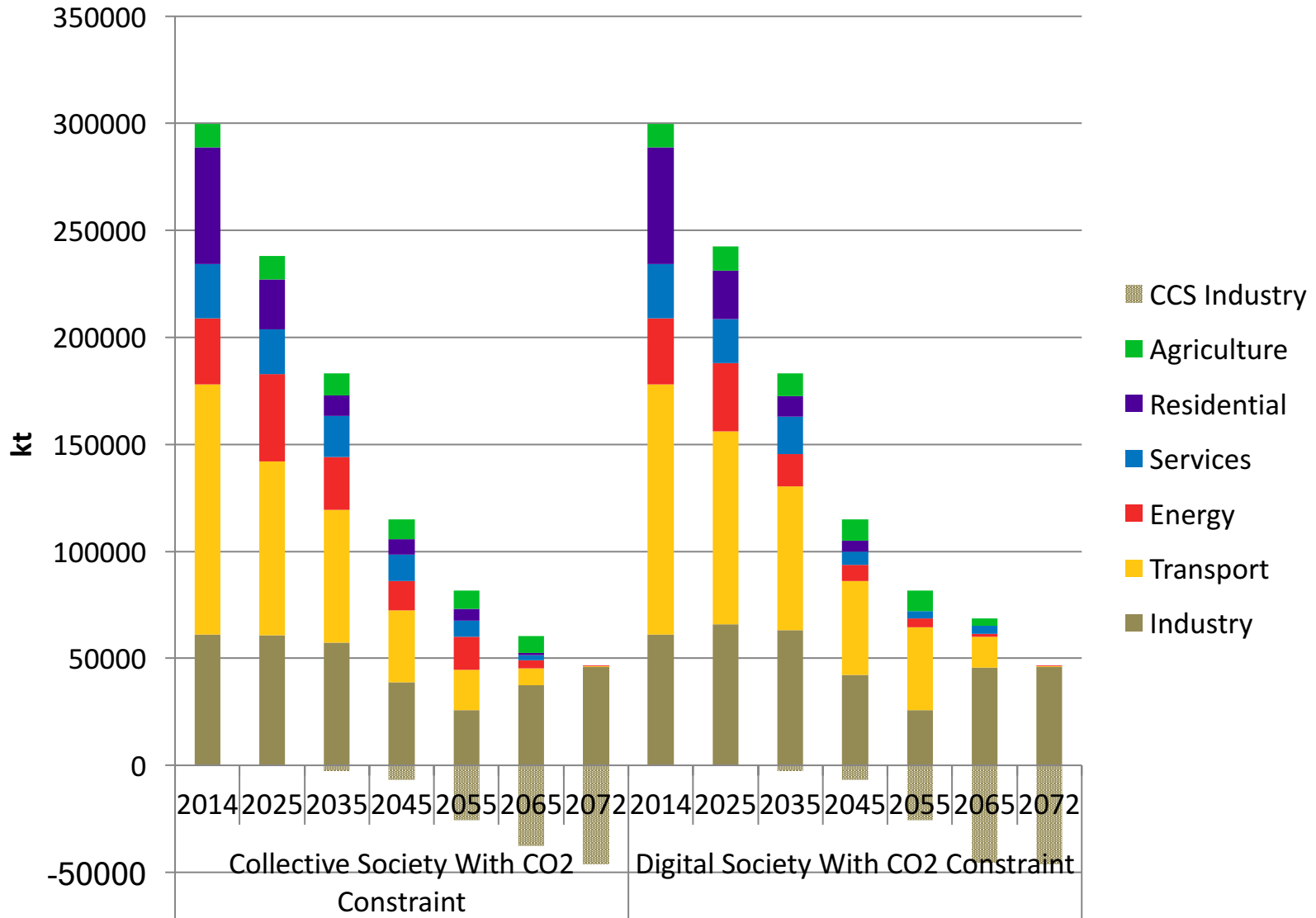
$$+ \sum_{k \in ENC} \sum_s cos$$

$$+ \sum_s \sum_{z \in Z} \sum_{y \in Y}$$

$$- \sum_s \sum_{z \in Z} \sum_{y \in Y}$$



# IN WHICH SECTORS ARE THE HIGHEST CO2 EMISSIONS REDUCTIONS?

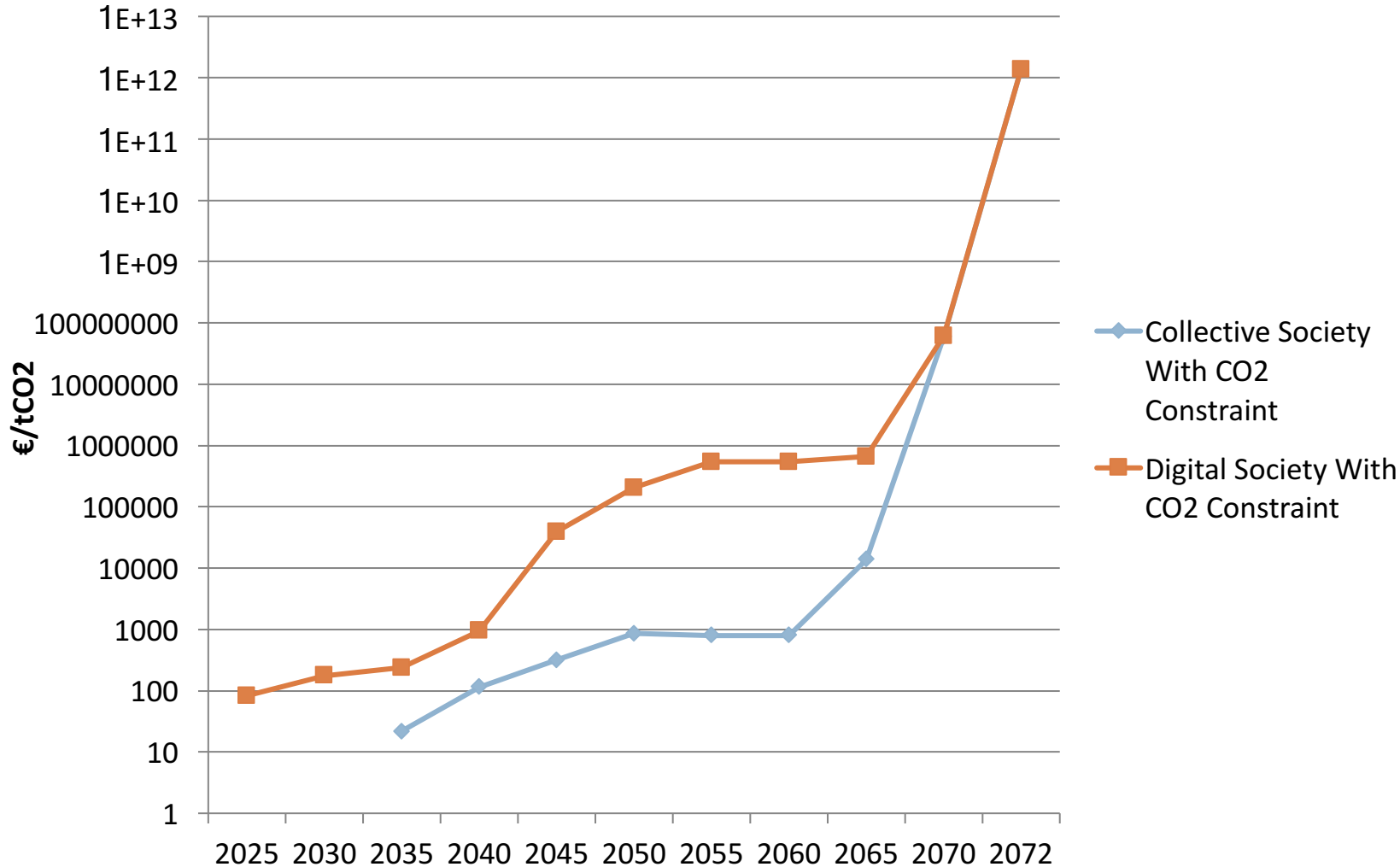


# BUT THE CO2 REDUCTION MAKES THE SYSTEM « OVERCONSTRAINED »

$$\frac{1}{(1+\alpha)^{n(t-1)}} \sum_{i \in TCH} in$$

$$\times \left( \sum_{i \in TCH} fixom_i(t) \right) + \sum_{i \in ELA} \sum_{z \in Z} \sum_{y \in Y} varc + \sum_{k \in ENC} \sum_s cos_{ks} + \sum_s \sum_{z \in Z} \sum_{y \in Y} price_{zy}$$

Marginal cost of CO2





# CONCLUSION & DISCUSSION



# CONCLUSION

- Methodology:
  - multi-dimensional approach combining lifestyles, economy and technologies
- Key findings:
  - Even the most sober lifestyle of our two scenarios does not reduce enough the CO2 emissions
  - Difficulty to reach neutrality :
    - Importance of lifestyle and its impact on demand (societal choice or economic pressure)
    - Importance of new technologies (CCS...)

# FUTURE WORK

- Constraint on CO2 emissions at a international level
- Sensitivity analysis of the end of horizon : 2050 instead of 2072
- Introduce more flexibility through interactions between energy vectors (power-to-gas, ...)





**THANK YOU FOR YOUR ATTENTION!**

[Ariane.millot@mines-paristech.fr](mailto:Ariane.millot@mines-paristech.fr)

[Remy.doudard@mines-paristech.fr](mailto:Remy.doudard@mines-paristech.fr)

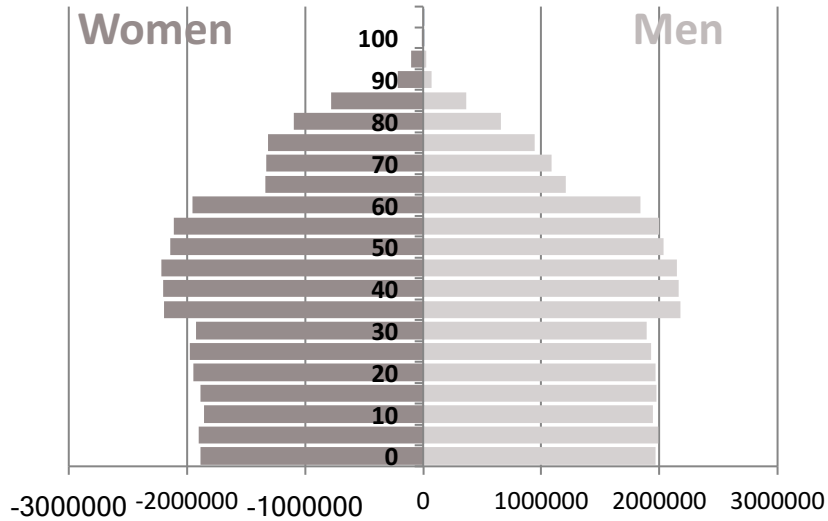


# APPENDICES

# HYPOTHESIS ON POPULATION



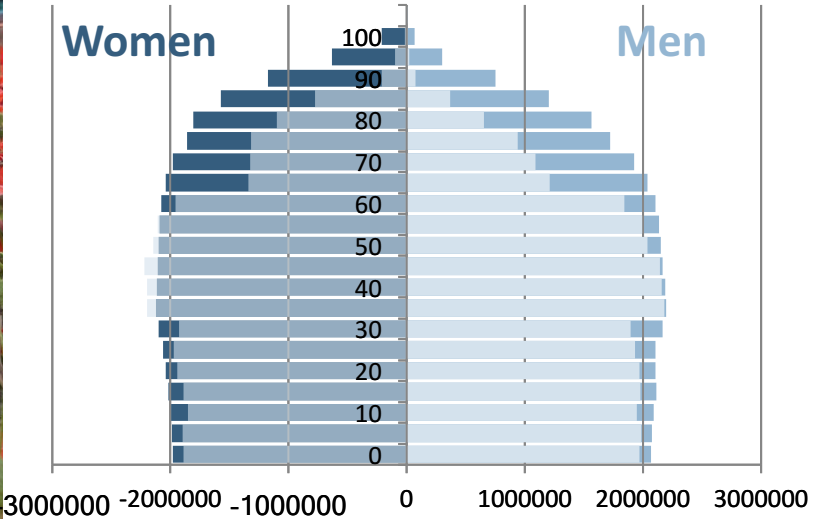
Situation in 2010



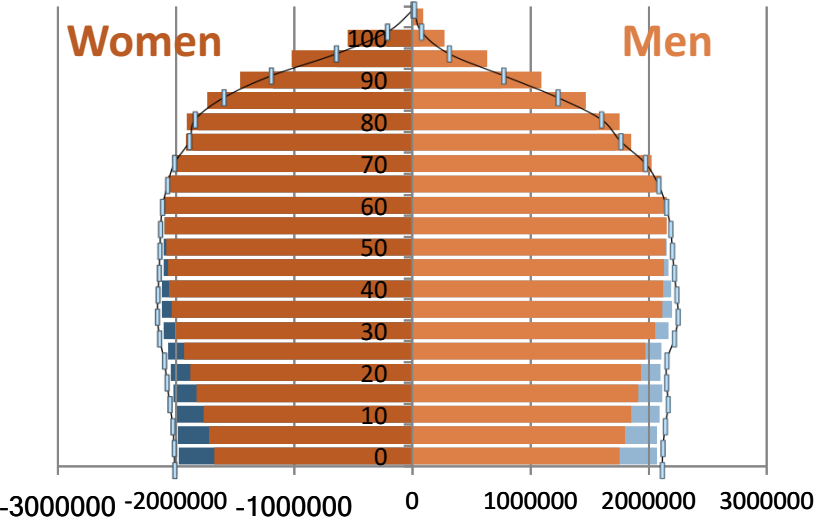
**+18%**

**... in 2072**

Scenario A & C



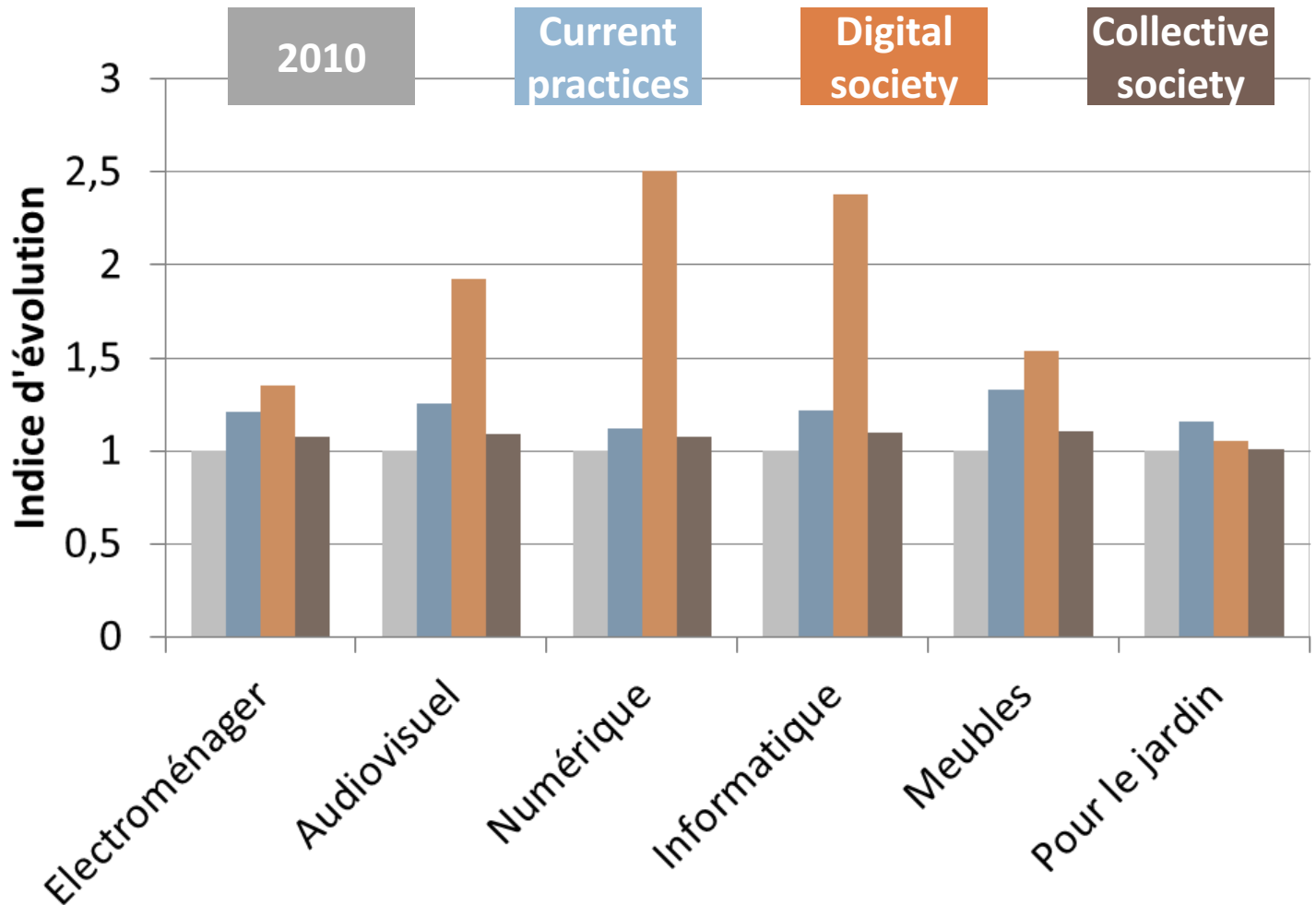
Scenario B





# INFLUENCE OF LIFESTYLES ON...

... consumption of equipments



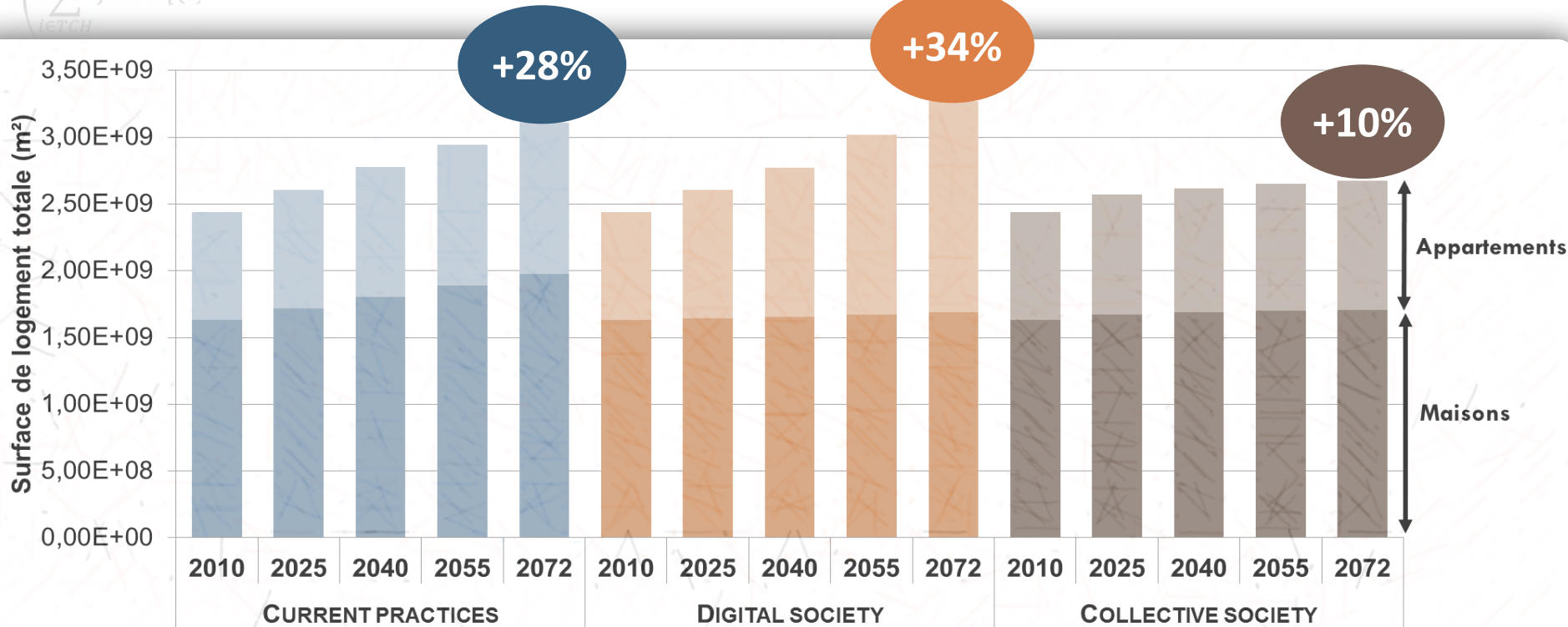
# INFLUENCE OF LIFESTYLES ON...



... housing demand

$$\frac{1}{(1 + \alpha)^{n(t-1)}} \sum_{i \in TCH} in$$

$$\times \left( \sum_{i \in TCH} fixom_i(t) \right)$$



**+18%**

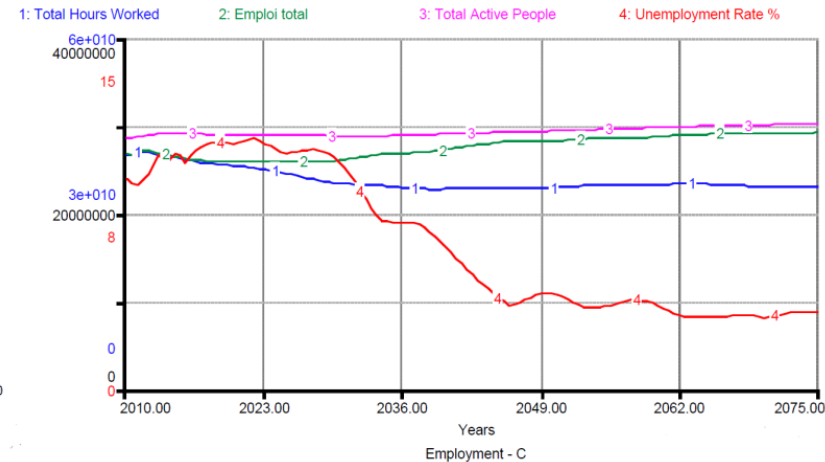
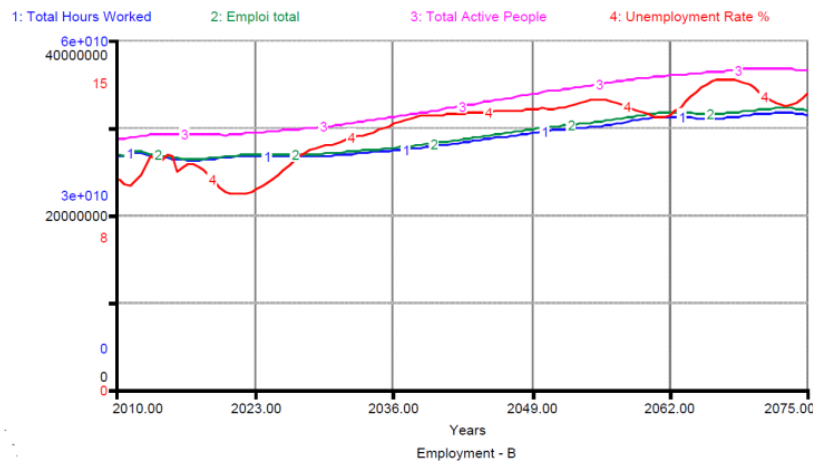
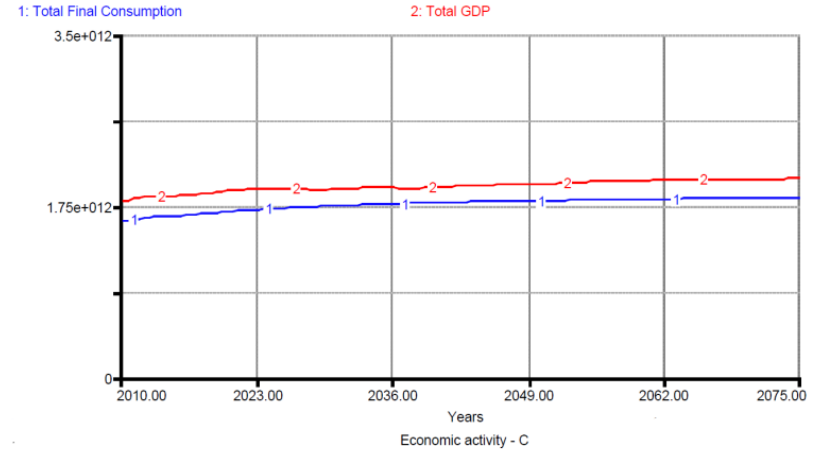
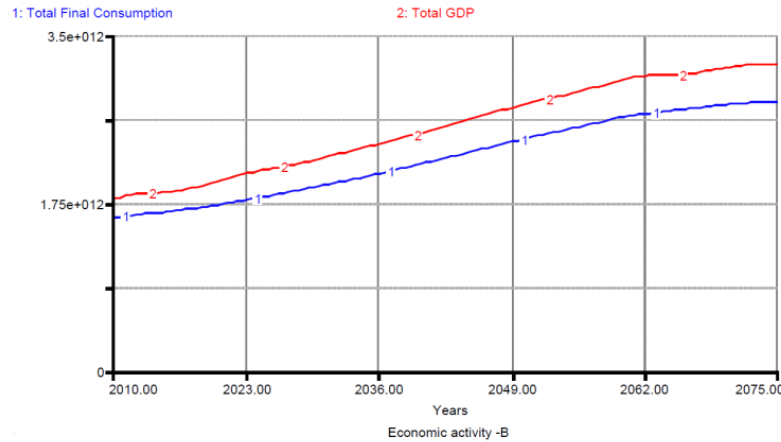
... in 2072

Population growth: +18%

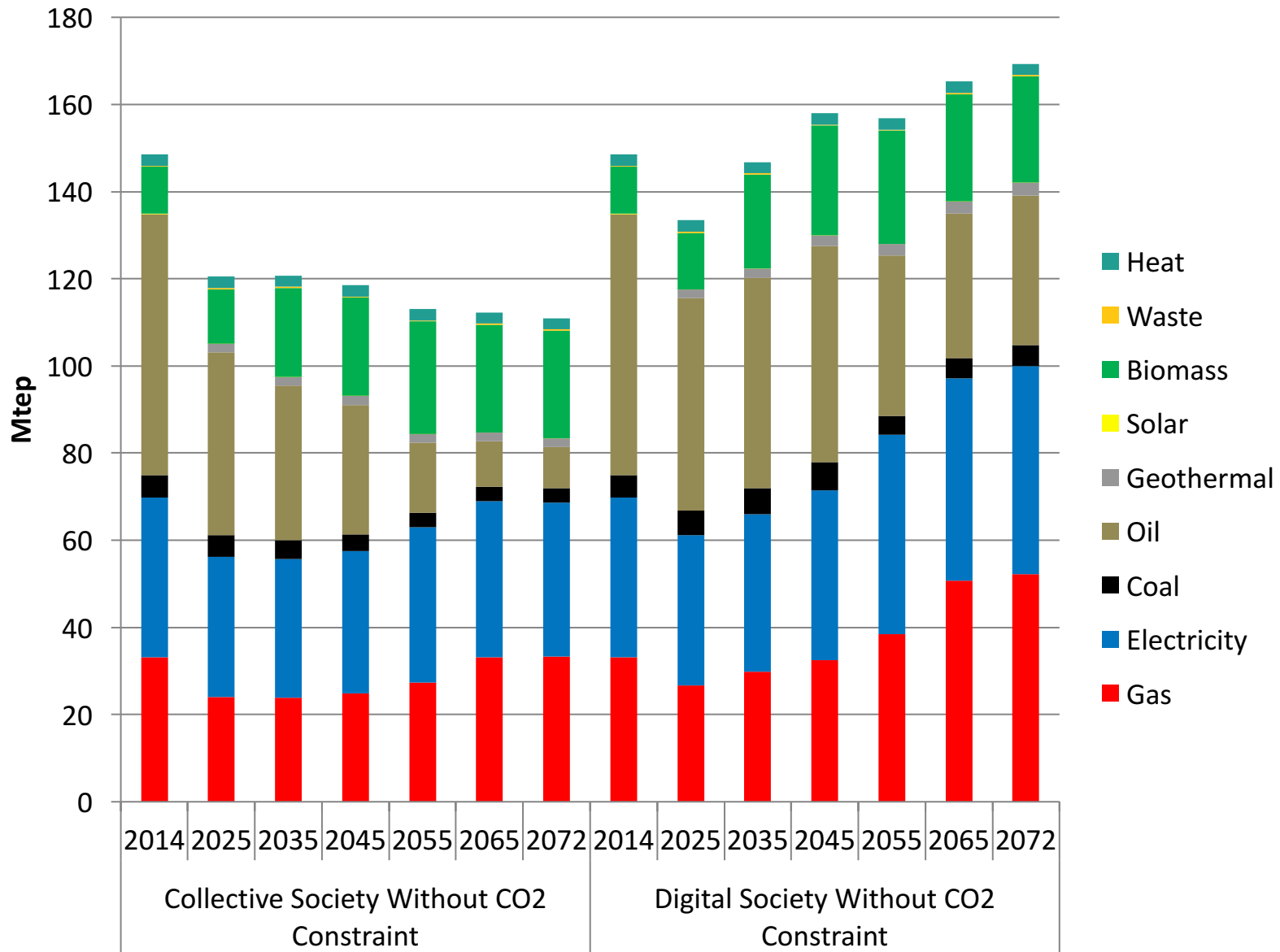
# DEMAND DRIVER FOR TIMES : RESULT OF THE INPUT-OUTPUT ANALYSIS

Scenario Digital Society

Scenario Collective Society



# ENERGY MIX



# ENERGY MIX

