Qualitative and Quantitative Assessment of New Paradigms and Challenges for Urban Energy Systems

Program "The Future of Energy"

Final workshop

17 January 2017

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Agenda

1. **About Enerdata**
2. **Introduction** to the research work
3. **Part 1: Literature Review** on current paradigms and future key challenges
4. **Part 2: Model-based Quantitative Assessment** of urban energy systems with the example of Grenoble Alpes Métropole
5. **Conclusions and Perspectives**
6. **Q/A**

1. About Enerdata

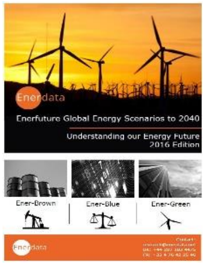
- A Global Energy Intelligence Company
- Fields of Expertise

A Global Energy Intelligence Company

- **Independent** energy research & consulting company since 1991
- Spin-off of CNRS research centre
- **Expert** in analysis and forecasting of global energy & climate issues
- **In-house** and globally recognised databases and forecasting models
- Headquartered in the Grenoble (French Alps) research cluster
- Offices in Paris, London and Singapore + network of partners worldwide
- **Global reach**: clients in Europe, Asia, Americas, Africa

Fields of Expertise

- Energy Efficiency & Demand
  - Analysis & Forecasting of energy demand by end use and energy efficiency
  - Policy evaluation & simulation
- Market Study
  - Market Assessment in developed and developing countries
  - Due diligence, feasibility studies
- Global Energy Markets
  - Analysis & Forecasting (drivers, supply/demand, prices)
  - Energy & Climate policy shaping
  - Power generation



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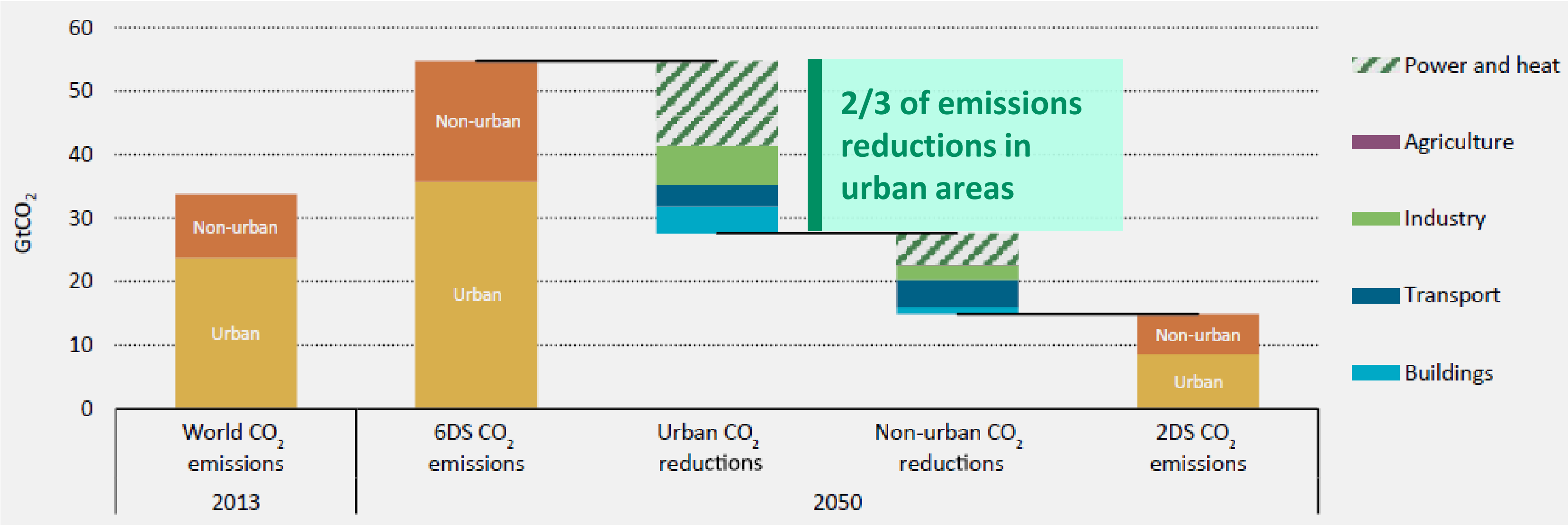
2. Introduction to the Research Work

- Context
- Objective
- Overall approach

Context

- Growing role of urban areas as a contributor to meet energy and climate objectives
- In 2013, cities concentrate:
  - 64% of global primary energy use
  - 70% of the global total CO_2 emissions
- In 2050, cities may
  - Generate 84% of GDP (which may triple over the period)
  - Experience a 62% increase of population



Objective

Identify, understand and assess the future challenges of urban energy systems

- Local integration of urban areas (Topic 1 of the Call)
  - Understand energy demand in detail (sectors, end-uses, temporality)
  - Explore possible energy supply solutions, including innovative ones

- Role of mobility (Topic 3 of the Call)
  - Focus on the role of electric vehicles
  - Possible impact on local demand and supply

Overall Approach

1. Literature review on current paradigm shifts and future challenges
   - Understand the current dynamics impacting urban energy systems, along with its drivers
   - Synthesise which main trends or parameters prove to be considered to assess properly urban energy systems and their sustainability

2. Model-based quantitative analysis with the example of Grenoble Aples Métropole
   - Construction of three scenarios
   - Assessment of future energy pathways and emerging trends & innovative solutions

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3. Part 1:
Literature Review
on current paradigms
and future key challenges

- Objective and methodology
- Results and key learnings

Objective

Identify the **paradigm shifts** impacting urban energy systems and the associated **challenges and solutions** for enhanced **sustainability**

- Better understanding of the **main drivers** of these changes to identify key dimensions and parameters to take into account
- Focus on existing **interdependencies and potential synergies** within urban energy systems (UES)

Methodology – Overview

- Underlying idea: identified changes should **reflect general trends** or concepts that can be applied for and replicated by the majority of cities
- At the same time, willingness to give voice to publications of different **stakeholders** (as embodied in the concept of sustainability)

→ Combined approach in 2 steps

0. Definition: what is a urban energy system (UES)?

Core topics

- Transformations impacting UES and drivers
- Challenges
- Associated solutions

1. Review of international publications with transversal approach

2. Focus on reports from non-academic authors, i.e. official city documents on strategy and sustainability plans. Restriction to 10 “exemplary” Eur. cities

Possibility to check if there is a gap between theoretical concepts and actions in cities

Methodology – Step 1

Criteria	Targets
Theme	Urban Energy systems: focus on definition, features, changes and challenges
Scope	General and systemic approach, no focus on a specific issue or type of city
Type	International publication
Authors	Internationally recognized experts, organisations or institutions from all backgrounds
Date	As recent as possible

Selected papers

Title	Author(s)	Date
Energy Technology Perspectives 2016	International Energy Agency (IEA)	2016
Renewable Energy in cities	International Renewable Energy Agency (IRENA)	2016
Advancing Toward a more Sustainable Urban Energy System- Policy and Technology Considerations	International Energy Agency (IEA) and World Resources Institute Ross Center for sustainable cities (WRI)	2015
Strategic Energy Technology Plan (SET)- Towards an Integrated roadmap: Research and Innovation Challenges and Needs of the EU Energy System	European Commission	2014
Energizing sustainable cities: assessing urban energy	A. Grubler and D. Fisk	2013
Energy Vision 2013- Energy transitions: Past and Future	World Economic Forum in Partnership with IHS CERA	2013
Urban Energy Systems- An integrated approach	J. Keirstead, N. Shah	2013
Challenges and ways forward in the urban sector	United Nations Department of Economic and Social Affairs (UNDESA)	2012
Global Energy Assessment- Toward a Sustainable Future	International Institute for Applied Systems Analysis (IIASA)	2012
Cities of tomorrow - Challenges, visions, ways forward	European Commission	2011

Methodology – Step 2

- Focus on local strategy plans from “exemplary” European cities (involved in European programs or labelled)

Name	Country	Label	Strategy and Action report/document used
Bolzano	Italy	Sinfonia	"Aktionsplan der Stadt Bozen für nachhaltige Energie" (APNE) (2010-2020)
Bristol	UK	European Green Capital	"The 20:20 plan: Bristol’s Sustainable City Strategy" (2009)/ "Bristol Climate Change Strategy" (2015)
Brussels	Belgium	European Green Capital	"Regional Air-Climate-Energy Plan" (2016)
Copenhagen	Denmark	European Green Capital	"CH 2025 Climate Plan" (2012)
Freiburg-im-Breisgau	Germany	European Green Capital	"Environmental Policy in Freiburg" (2011)/ "Klimaschutz-Strategie der Stadt Freiburg" (2007-2020)
Geneva	Switzerland	Concerto	"Politique énergétique et climatique de la ville de genève - Objectifs Politiques et Stratégiques- Plan d'actions 2014-2018"(2014)
Grenoble	France	Concerto	"Plan d'Action Air Energie Climat de la Ville de grenoble étape 2016-2020" (2016)
Hambourg	Germany	European Green Capital	"Master Klimatschutz – Zielsetzung, Inhalt und Umsetzung" (2013)
Ljubljana	Slovenia	European Green Capital	"Energy for the City of the Future- Presentation of the Sustainable Energy Action Plan of the City of Ljubljana" (2012)
Stockholm	Sweden	European Green Capital	"Stockholm action plan for climate and energy 2010–2020" (2009)

Results – Defining urban energy systems (UES)

- City? Urban area? No standardised definition so far
  → Necessity to explicit the **scope** of analysis
- Convergence towards a **systemic representation of cities as intricate and connected socio-economic, technical systems incl. the energy system**
- Thousands of articles dealing one specific aspect of energy in cities… but very few publications explicitly defining UES or identifying their specific features
- UES refer to **"the combined processes of acquiring and using energy to satisfy the energy service demands of a given urban area"** [Keirstead and Shah, 2013]

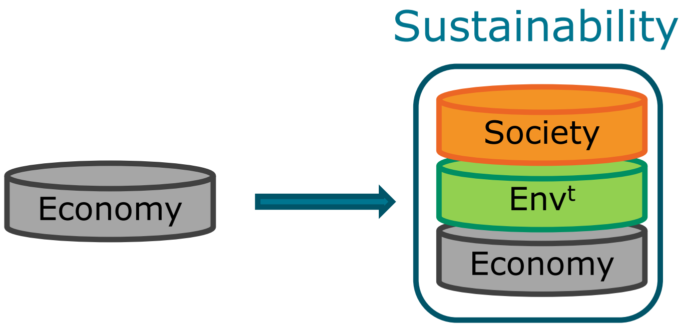
Results – Features of UES and drivers of energy use

- UES's **specific features** [IIASA, 2012]:
  - "high **density** of population, activities, and the resulting energy use and pollution"
  - "high degree of openness in terms of exchanges of **flows** of information, people, and resources, including energy"
  - "high concentration of economic and human capital **resources** that can be mobilised to institute innovation and transitional change"

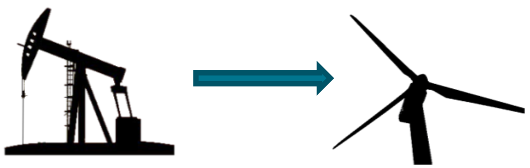
- Various drivers (natural, organisational, socioeconomic, etc.), but "no study so far has investigated the relative importance of all the factors known to influence urban energy use" [Grubler and Fisk, 2013]

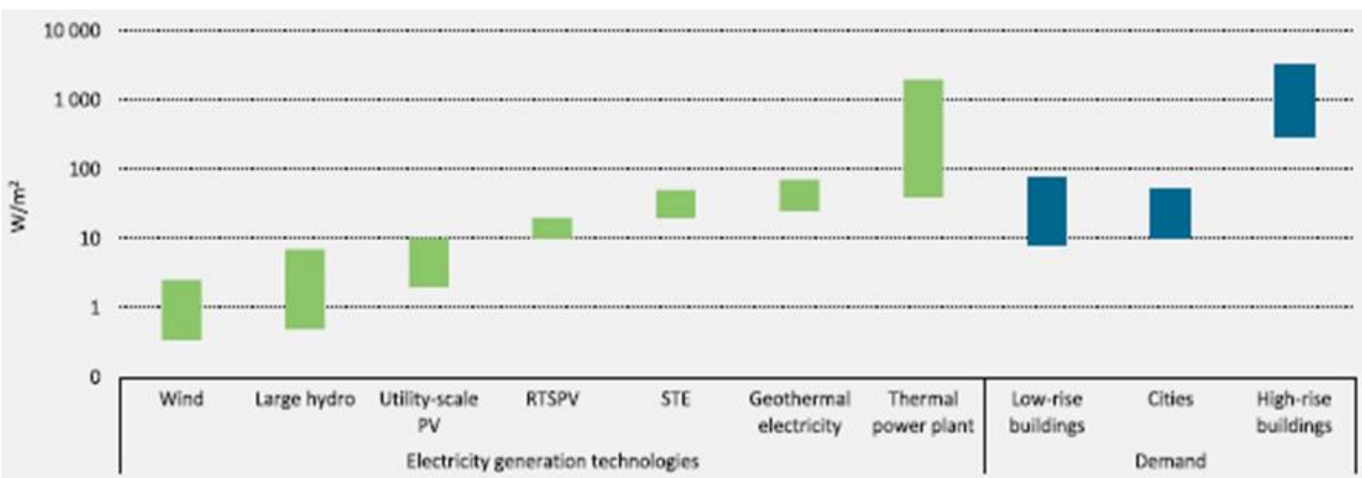
Results – Key paradigms impacting UES (1/2)

- From a cost-effective urban energy system to a « sustainable » urban energy system



- From fossil fuels-based central energy systems to distributed renewables energies… but implying energy density challenges

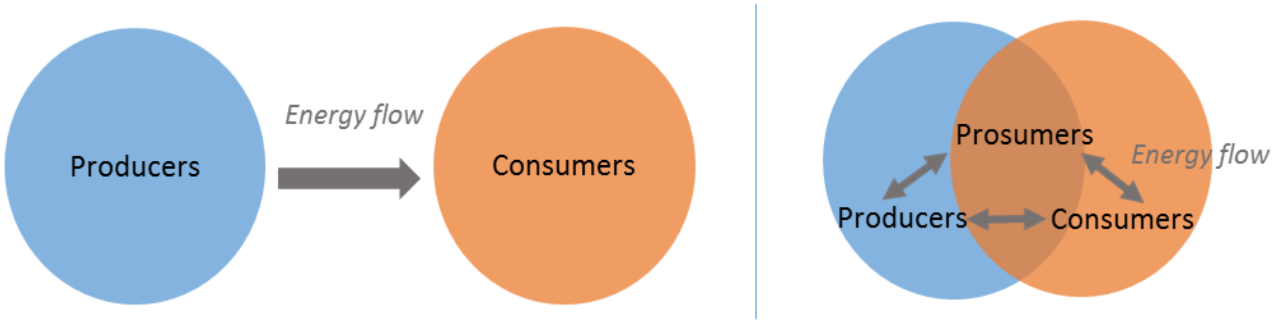




Source: IRENA, 2016

Results – Key paradigms impacting UES (2/2)

- From one-way production-consumption approach to multidirectional urban energy system based on “prosumers”



- From a central and top-down governance system to local shared decisions involving stakeholders

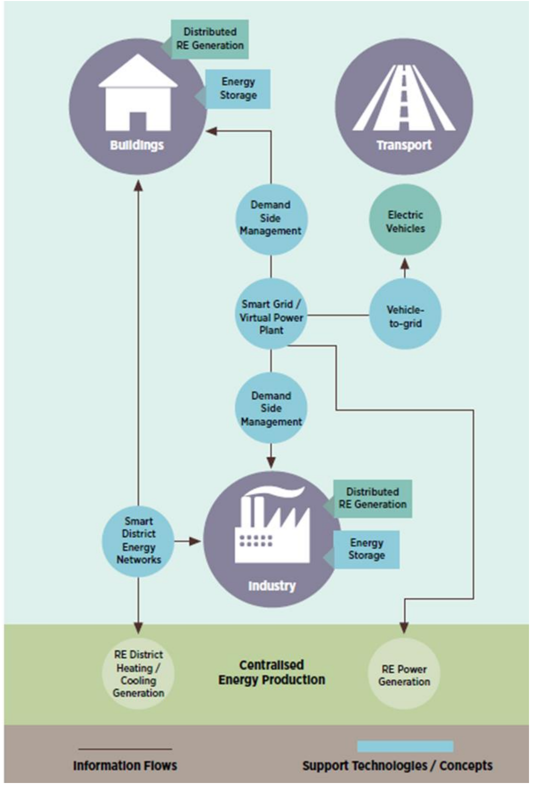
Results – Main challenges and solutions (1/2)

- **Affordable** and socially inclusive UES, taking into account all dimensions of **sustainability**
  - Need for a transversal approach and new indicators to monitor progress
  - Major issue of energy poverty, even in developed countries
- **Maintaining security, resilience and flexibility** of UES… thanks to/despite the growing share of RES and storage
  - Crucial role of integrated energy management tools and ICT, e.g. smart grids and demand-side management, Virtual Power Plants, flexible pricing, etc.
- **Increasing energy efficiency**: huge potentials in buildings and transport
  - Retrofitting buildings can reduce heating and cooling energy requirements by 50-90% [IIASA,2012]
  - Transport: “avoid-shift-improve” and electrification
  - Importance of behavioural change

Results – Main challenges and solutions (2/2)

- Need for an **integrated system** as basis for further optimisation
  - Role of EVs as interconnections between transport and power
  - Role of multiple energy carriers' solutions and conversion efficiency
  - Necessity of a flexible and multi-scale governance scheme

- **Empowering stakeholders** and ensuring participation: "innovative use of social capital are needed" [European Union, 2011]



Source: IRENA, 2016

But: assessment extremely difficult without robust urban data

Results – Cities in action

- **Integrated approach** for a transition towards sustainability: large vision incl. water, food, procurement schemes, etc.
- Strong role of the city as **initiator** and enabler: "leading by good example"
- Favoured actions
  - Development of local RES seen as a pre-requisite
  - Buildings retrofit
  - Development of public transport
- But **primary focus on measures with direct impact and limited costs** Further savings and technology innovations (as identified in the literature) still possible

Key learnings from literature review

- Need for a **deep granularity** in the analysis of urban energy systems: representing buildings and districts; ideally have access to households data

- Capturing **synergy and optimisation potentials** at **all levels**
  … which in turn induce new optimisation decision from prosumers

- **Integrated approach** of urban energy systems: taking environmental, social and economic aspects into account
  - Necessity of a systemic approach
  - Need for new indicators to track accurately progress towards more sustainability

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4. Part 2:
Model-based Quantitative Assessment
of urban energy systems with the example of Grenoble Alpes Métropole

- Methodological overview: EnerCity model
- Model interface and scenarios
- Results

Overall model structure

LEVEL 3: AGGLOMERATION

- Entity observed: agglomeration as a whole (as a consuming and producing entity)
- Modelling: valorisation of resources, role of industry and transport sectors
- Data required: availability of resources, historic industry consumption by branch, etc.

LEVEL 2: DISTRICT

- Entity observed: buildings groups, residential areas, etc.
- Modelling: aggregation and structuration of energy flows at quarter level, incl. mutualisation effects
- Data required: typology of zones, costs of district heating, etc.

LEVEL 1: BUILDING

- Entity observed: detailed buildings' typology
- Modelling: minimisation of global building energy cost including externalities
- Data required: current equipment rates, specific energy consumptions, etc.

Buildings: bottom-up demand modelling

Detailed typology

- Residential : 45 typical buildings (3 types, 5 construction periods, 3 sizes)
- Services : 45 typical buildings (9 activity types, 5 construction periods)

Description of typical buildings

- Physical characteristics (heat losses, surfaces), climate zone, historical equipment rates, size of households, number of employees, working hours, etc.

Energy demand end-uses

- Cooking, hot water, heating, cooling, captive electricity, lighting, other thermal uses (tertiary buildings)

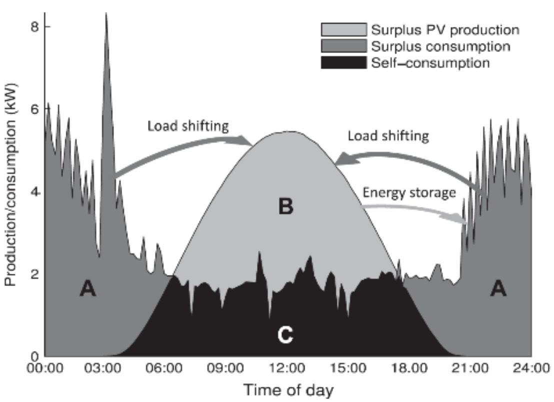
Buildings: model logics for the residential sector

For each of the 45 typical buildings

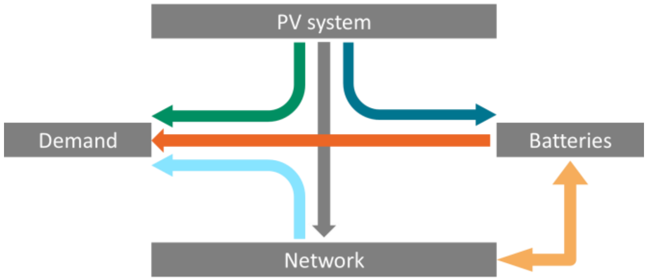
Demand by end-use ↓	Bottom-up (inspired from MedPro model)
Full costs by technology ↓	Investment, variable cost, net renovation cost, subsidies
Competition ↓	Logit function (pseudo-optimisation inspired from POLES)
Equipment renewal ↓	Scrapping rate & new demand (inspired from POLES)
Load curves	On 8 typical days (4 seasons x 2 days (WD/WE))

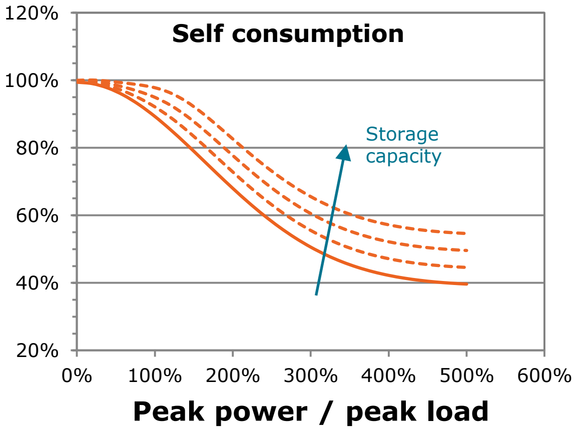
Buildings: decentralised supply and storage

- Solar PV production: calculated from available surface after dimensioning of thermal solar surface
- Batteries : dimensioned based on PV production and demand level



$$\text{Self consumption} = \frac{\text{Consumed production}}{\text{Total production}}$$





$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x}{\sigma}\right)^2} + \frac{K}{1 + ae^{-rt}}$$

Enerdata

Buildings: decision-making for PV

- *Sale without self-consumption (case 1)*

COSTPV1 = ((**LCOEPV**[AGE,TYPE,SIZE] - **FiT**) * **PRODPV**[AGE,TYPE,SIZE] + **PRC**[ELE] * **DEMBAT**[AGE,TYPE,SIZE,ELE]) / **DEMBAT**[AGE,TYPE,SIZE,ELE]

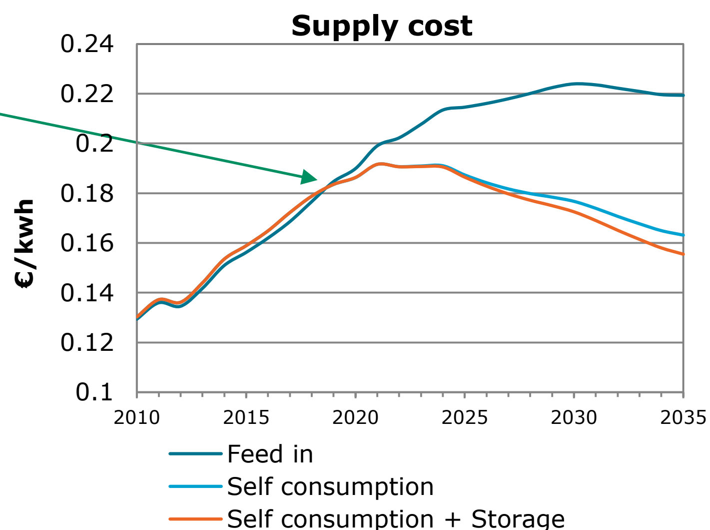
- *Self-consumption and sale of surplus (case 2)*

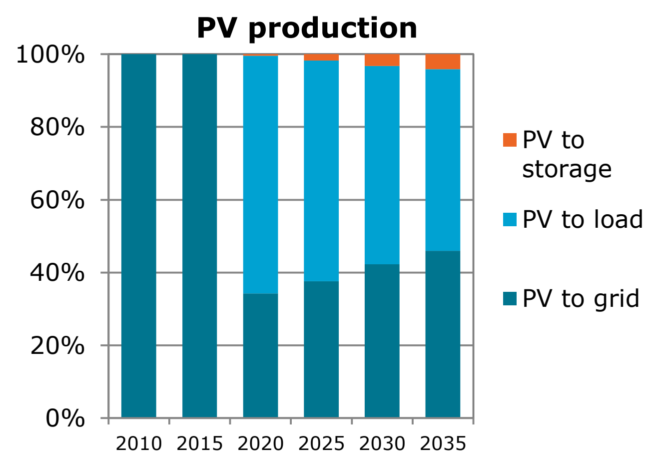
COSTPV2 = ((**LCOEPV**[AGE,TYPE,SIZE] - (1 – **SLFCSMPV1**[AGE,TYPE,SIZE]) * **FiT**) * **PRODPV**[AGE,TYPE,SIZE] + **DEMBAT**[AGE,TYPE,SIZE,ELE] * (1 – **SLFPRODPV1**[AGE,TYPE,SIZE]) * **PRC**[ELE]) / **DEMBAT**[AGE,TYPE,SIZE,ELE]

- *Self-consumption, sale of surplus and storage (case 3)*

COSTPV3 = ((**LCOEPV**[AGE,TYPE,SIZE] + **XSTO** * **LCOS**[AGE,TYPE,SIZE] – (1 – **SLFCSMPV2**[AGE,TYPE,SIZE]) * **FiT**) * PRODPV[AGE,TYPE,SIZE] + **DEMBAT**[AGE,TYPE,SIZE,ELE] * (1 – **SLFPRODPV**[AGE,TYPE,SIZE]) * **PRC**[ELE]) / **DEMBAT**[AGE,TYPE,SIZE,ELE]

Parity, depending on feed-in tariffs and storage costs





Districts: definition of unitary districts (1 km²)

- Residential: number of dwellings by age, type and size
- Services: surface by age and activity type

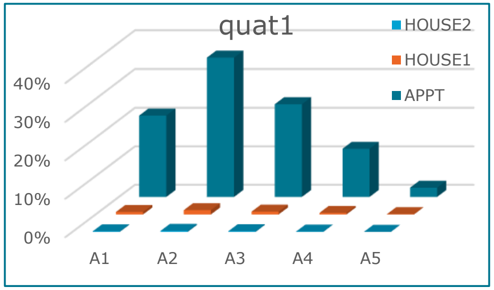
District	Residential density (households/km²)	Tertiary density (10^3 m²/km²)
Quat1	2513	180.8
Quat2	634	43.6
Quat3	997	89.9
Quat4	51	1.4

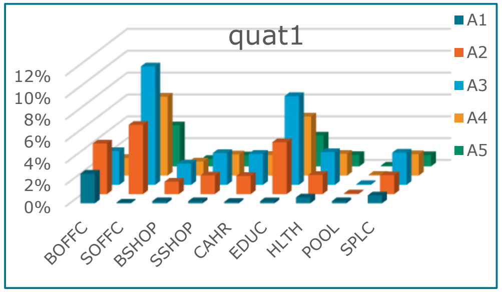
- Quat1 : inner centre
- Quat2 : first-ring suburbs
- Quat3 : second-ring suburbs
- Quat4 : peri-urban districts

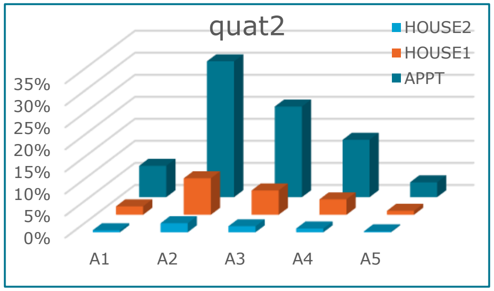
- A1 : before 1946
- A2 : 1946-1974
- A3 : 1975-1989
- A4 : 1990-2008
- A5 : after 2009

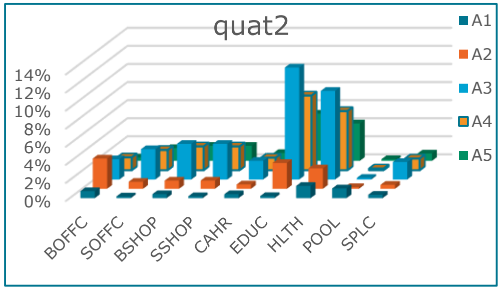
Residential : % number of dwellings

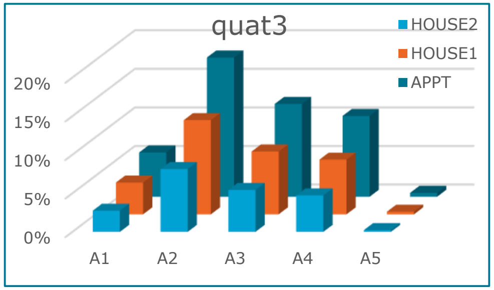
Services : % surfaces

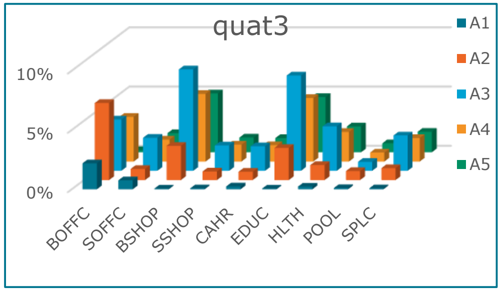


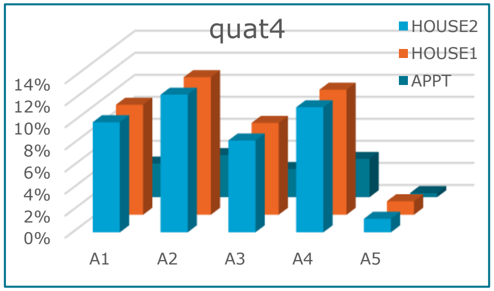


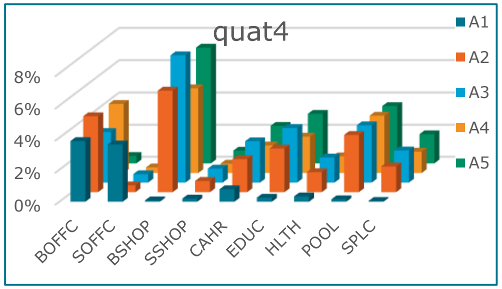








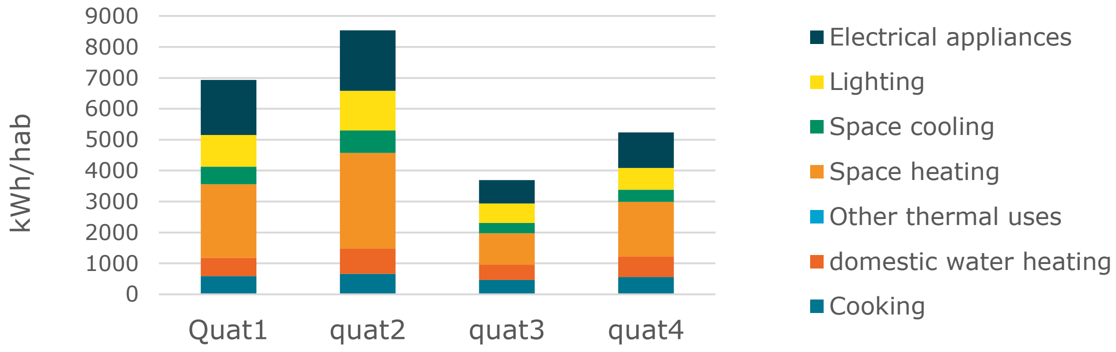




Districts: structuration of flows and mutualisation

Aggregation of flows for energy demand and decentralised supply

- Linear combination of districts' building components



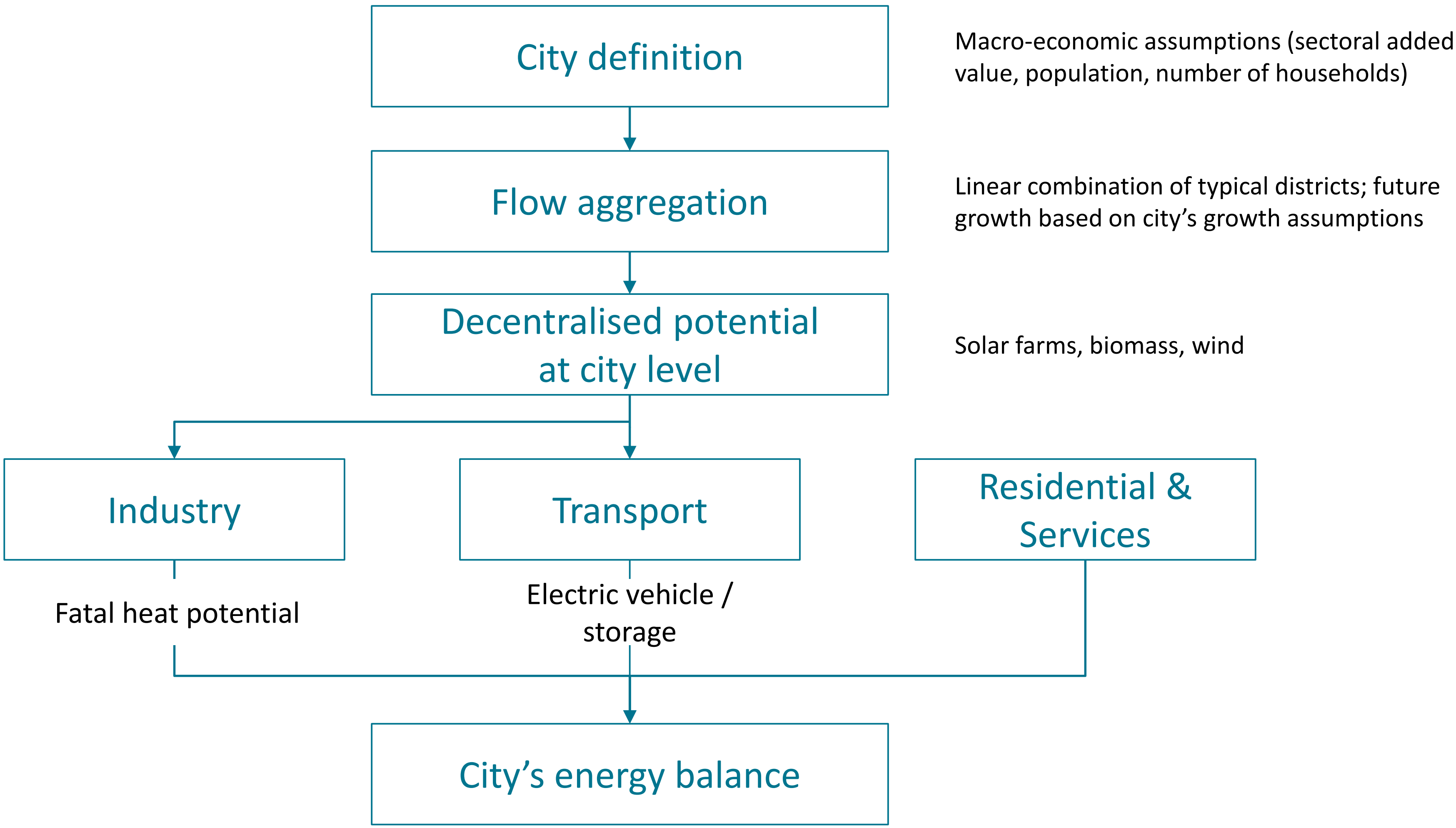
Resources mutualisation

- Self-consumption of PV production
- Aggregation PV production fed in to the network (PV-to-grid)

Calculation of market shares at district level

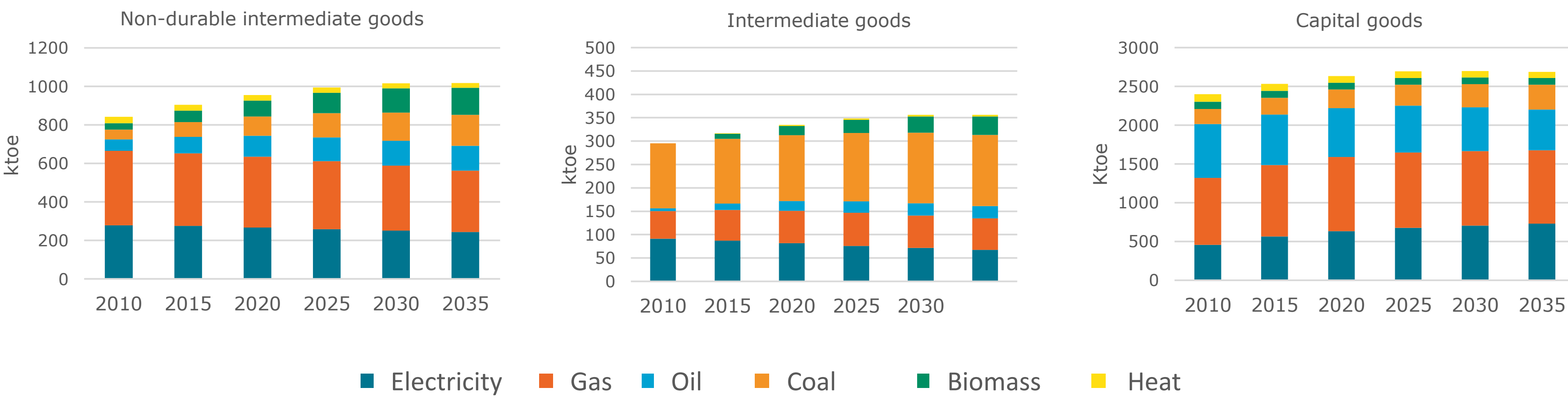
- Depend on buildings (residential & teritiary) constituting the district
- Heating and hot water: consideration of competitiveness of district heating solutions (dimensioned in the model)

City: model structure



City: industry

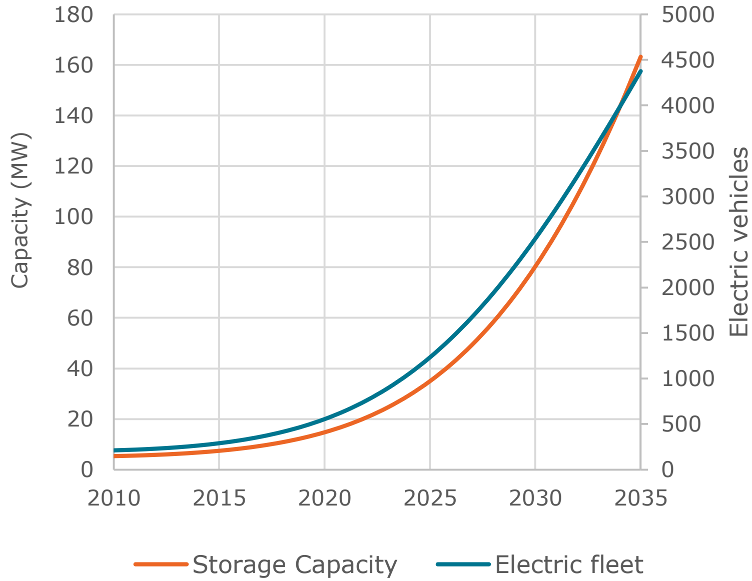
- Three industry branches
  - Non-durable intermediate goods: agribusiness, paper, textiles, etc.
  - Intermediate goods: metals, non-metallic minerals, chemistry, etc.
  - Capital goods: mechanic and electric industry, automotive, aeronautics, marine industry, etc.
- For each branch, energy demand evolves based on its added value and energy intensity



City: transport

- Three sub-sectors
  - Private passengers transport
  - Public passengers transport
  - Transport of goods

- Calculation of additional storage capacity to be made available by electric vehicles (private cars and light duty)



4. Part 2:
Model-based Quantitative Assessment
of urban energy systems with the example of Grenoble Alpes Métropole

- Methodological overview: EnerCity model
- Model interface and scenarios
- Results

Software architecture

EnerCity model relies on following elements:

- A **program code** of about 8,000 lines, developed in Vensim (from Ventana Systems)
- A MS-Excel **user interface** containing
  - All **input data**, structured by observation level and topic
  - An **automatic user interface**, developed in VBA for MS-Excel, to manage scenarios, start runs and visualise results

Interface: input databases

Var	Sub1	Sub2	Sub3	Sub4	TIME	2010	2011	2012	2013	2014
DJU DAT	AUTUMN				DJU DAT[AUTUMN]	661	482	538	583	404
DJU DAT	WINTER				DJU DAT[WINTER]	1536	1275	1474	1428	1188
DJU DAT	SPRING				DJU DAT[SPRING]	661	548	633	824	659
DJU DAT	SUMMER				DJU DAT[SUMMER]	0	0	0	0	0
HTLOS DAT	A1	APPT			HTLOS DAT[A1,APPT]	0.9	0.9	0.9	0.9	0.9
HTLOS DAT	A1	HOUSE1			HTLOS DAT[A1,HOUSE1]	1	1	1	1	1
HTLOS DAT	A1	HOUSE2			HTLOS DAT[A1,HOUSE2]	0.95	0.95	0.95	0.95	0.95
HTLOS DAT	A2	APPT			HTLOS DAT[A2,APPT]	0.95	0.95	0.95	0.95	0.95
HTLOS DAT	A2	HOUSE1			HTLOS DAT[A2,HOUSE1]	1.05	1.05	1.05	1.05	1.05
HTLOS DAT	A2	HOUSE2			HTLOS DAT[A2,HOUSE2]	1	1	1	1	1
HTLOS DAT	A3	APPT			HTLOS DAT[A3,APPT]	0.75	0.75	0.75	0.75	0.75
HTLOS DAT	A3	HOUSE1			HTLOS DAT[A3,HOUSE1]	0.85	0.85	0.85	0.85	0.85
HTLOS DAT	A3	HOUSE2			HTLOS DAT[A3,HOUSE2]	0.8	0.8	0.8	0.8	0.8
HTLOS DAT	A4	APPT			HTLOS DAT[A4,APPT]	0.65	0.65	0.65	0.65	0.65
HTLOS DAT	A4	HOUSE1			HTLOS DAT[A4,HOUSE1]	0.75	0.75	0.75	0.75	0.75
HTLOS DAT	A4	HOUSE2			HTLOS DAT[A4,HOUSE2]	0.7	0.7	0.7	0.7	0.7
HTLOS DAT	A5	APPT			HTLOS DAT[A5,APPT]	0.5	0.5	0.5	0.5	0.5
HTLOS DAT	A5	HOUSE1			HTLOS DAT[A5,HOUSE1]	0.6	0.6	0.6	0.6	0.6
HTLOS DAT	A5	HOUSE2			HTLOS DAT[A5,HOUSE2]	0.55	0.55	0.55	0.55	0.55
LIFSPH DAT	ELEHT				LIFSPH DAT[ELEHT]	25				
LIFSPH DAT	ELEPCHT				LIFSPH DAT[ELEPCHT]	25				
LIFSPH DAT	GASHT				LIFSPH DAT[GASHT]	25				

Interface: scenario management

Create target

Target path	W:\Common work\CFE\Test\Vensim\MODEL\
Name of the new target	Grenoble_20160718
Number of tabs for target	26
Sheet before first tab	Target

Command script

Path:	W:\Common work\CFE\Test\Vensim\MODEL\
Run:	BOUCLAGE_9
Liste Var:	Grenoble_20160718
Model:	Quartier20160718_1.mdl
Début simu:	2010
Fin simu:	2035
.cin	
Run d'origine	
Scenario	

Scenarios

Scenario 1	W:\Common work\CFE\Test\Vensim\MODEL\BOUCLAGE_7
Scenario 2	W:\Common work\CFE\Test\Vensim\MODEL\BOUCLAGE_9
Scenario 3	W:\Common work\CFE\Test\Vensim\MODEL\BOUCLAGE_3_9
Scenario 4	W:\Common work\CFE\Test\Vensim\MODEL\BOUCLAGE_3_8
Scenario 5	W:\Common work\CFE\Test\Vensim\MODEL\BOUCLAGE_3_4

Show All Worksheets

Hide

Clear all

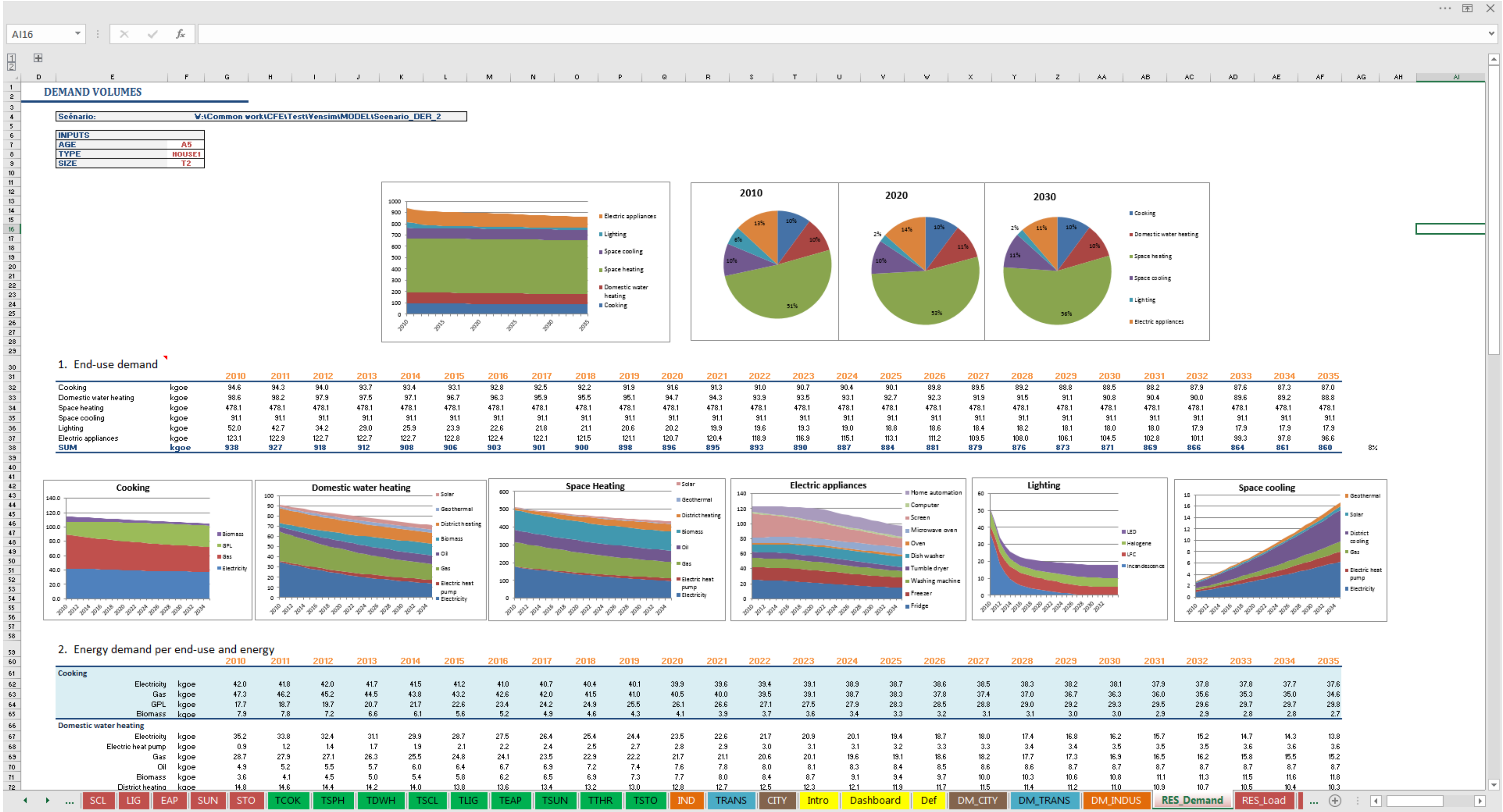
Create target

Create Var file

Run test

release VDF

Interface: results visualisation



1. End-use demand

		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Cooking	kgoe	94.6	94.3	94.0	93.7	93.4	93.1	92.8	92.5	92.2	91.9	91.6	91.3	91.0
Domestic water heating	kgoe	98.6	98.2	97.9	97.5	97.1	96.7	96.3	95.9	95.5	95.1	94.7	94.3	93.9
Space heating	kgoe	478.1	478.1	478.1	478.1	478.1	478.1	478.1	478.1	478.1	478.1	478.1	478.1	478.1
Space cooling	kgoe	91.1	91.1	91.1	91.1	91.1	91.1	91.1	91.1	91.1	91.1	91.1	91.1	91.1
Lighting	kgoe	52.0	42.7	34.2	29.0	25.9	23.9	22.6	21.8	21.1	20.6	20.2	19.9	19.6
Electric appliances	kgoe	123.1	122.9	122.7	122.7	122.7	122.8	122.4	122.1	121.5	121.1	120.7	120.4	118.9
SUM	**kgoe**	**938**	**927**	**918**	**912**	**908**	**906**	**903**	**901**	**900**	**898**	**896**	**895**	**893**

		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	
Cooking	kgoe	90.7	90.4	90.1	89.8	89.5	89.2	88.8	88.5	88.2	87.9	87.6	87.3	87.0	
Domestic water heating	kgoe	93.5	93.1	92.7	92.3	91.9	91.5	91.1	90.8	90.4	90.0	89.6	89.2	88.8	
Space heating	kgoe	478.1	478.1	478.1	478.1	478.1	478.1	478.1	478.1	478.1	478.1	478.1	478.1	478.1	
Space cooling	kgoe	91.1	91.1	91.1	91.1	91.1	91.1	91.1	91.1	91.1	91.1	91.1	91.1	91.1	
Lighting	kgoe	19.3	19.0	18.8	18.6	18.4	18.2	18.1	18.0	18.0	17.9	17.9	17.9	17.9	
Electric appliances	kgoe	116.9	115.1	113.1	111.2	109.5	108.0	106.1	104.5	102.8	101.1	99.3	97.8	96.6	
SUM	**kgoe**	**890**	**887**	**884**	**881**	**879**	**876**	**873**	**871**	**869**	**866**	**864**	**861**	**860**	8%

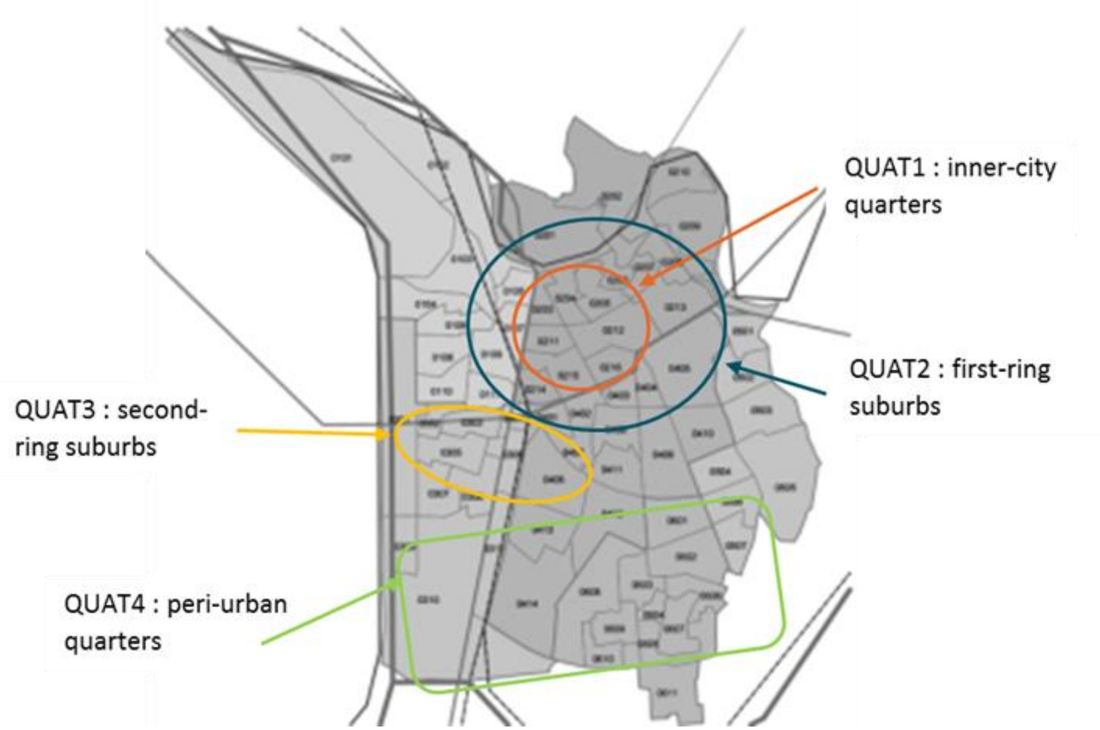
2. Energy demand per end-use and energy

		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Cooking														
Electricity	kgoe	42.0	41.8	42.0	41.7	41.5	41.2	41.0	40.7	40.4	40.1	39.9	39.6	39.4
Gas	kgoe	47.3	46.2	45.2	44.5	43.8	43.2	42.6	42.0	41.5	41.0	40.5	40.0	39.5
GPL	kgoe	17.7	18.7	19.7	20.7	21.7	22.6	23.4	24.2	24.9	25.5	26.1	26.6	27.1
Biomass	kgoe	7.9	7.8	7.2	6.6	6.1	5.6	5.2	4.9	4.6	4.3	4.1	3.9	3.7
Domestic water heating														
Electricity	kgoe	35.2	33.8	32.4	31.1	29.9	28.7	27.5	26.4	25.4	24.4	23.5	22.6	21.7
Electric heat pump	kgoe	0.9	1.2	1.4	1.7	1.9	2.1	2.2	2.4	2.5	2.7	2.8	2.9	3.0
Gas	kgoe	28.7	27.9	27.1	26.3	25.5	24.8	24.1	23.5	22.9	22.2	21.7	21.1	20.6
Oil	kgoe	4.9	5.2	5.5	5.7	6.0	6.4	6.7	6.9	7.2	7.4	7.6	7.8	8.0
Biomass	kgoe	3.6	4.1	4.5	5.0	5.4	5.8	6.2	6.5	6.9	7.3	7.7	8.0	8.4
District heating	kgoe	14.8	14.6	14.4	14.2	14.0	13.8	13.6	13.4	13.2	13.0	12.8	12.7	12.5

		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Cooking														
Electricity	kgoe	39.1	38.9	38.7	38.6	38.5	38.3	38.2	38.1	37.9	37.8	37.8	37.7	37.6
Gas	kgoe	39.1	38.7	38.3	37.8	37.4	37.0	36.7	36.3	36.0	35.6	35.3	35.0	34.6
GPL	kgoe	27.5	27.9	28.3	28.5	28.8	29.0	29.2	29.3	29.5	29.6	29.7	29.7	29.8
Biomass	kgoe	3.6	3.4	3.3	3.2	3.1	3.1	3.0	3.0	2.9	2.9	2.8	2.8	2.7
Domestic water heating														
Electricity	kgoe	20.9	20.1	19.4	18.7	18.0	17.4	16.8	16.2	15.7	15.2	14.7	14.3	13.8
Electric heat pump	kgoe	3.1	3.1	3.2	3.3	3.3	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6
Gas	kgoe	20.1	19.6	19.1	18.6	18.2	17.7	17.3	16.9	16.5	16.2	15.8	15.5	15.2
Oil	kgoe	8.1	8.3	8.4	8.5	8.6	8.6	8.7	8.7	8.7	8.7	8.7	8.7	8.7
Biomass	kgoe	8.7	9.1	9.4	9.7	10.0	10.3	10.6	10.8	11.1	11.3	11.5	11.6	11.8
District heating	kgoe	12.3	12.1	11.9	11.7	11.5	11.4	11.2	11.0	10.9	10.7	10.5	10.4	10.3

Project's case study: Grenoble Alpes Métropole

- Administrative boundaries of Grenoble Alpes Métropole
  - 49 communes
  - About 450,000 inhabitants (as of 2015) over a territory of 541.17 km^2



Scenario overview

Business as Usual (BAU)

Based on present local thermal regulations and current subsidies levels on distributed energies (e.g. “Mur-Mur” thermal renovation campaign over 2011-2014 for buildings). Moderate technological progress assumed.

Energy Efficiency Scenario (EE)

More ambitious energy policies and faster technological progress to reduce final energy demand and optimise energy distribution: retrofit and inner temperature control in buildings; increased efficiency of conventional cars and development of EVs and hybrid vehicles, modal shift to public transport; efficiency in industry processes

Decentralised Energies Scenario (DER)

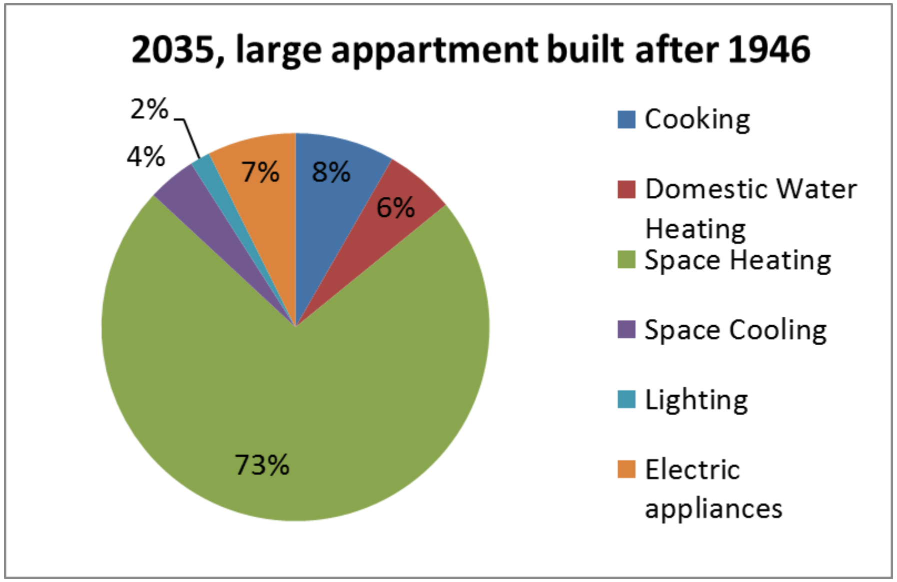
Abundant distributed energy generation thanks to higher incentives compared to BAU. Additional investments are realised to expand the district heating and cooling networks. Enhanced mutualisation of energy supply and demand through aggregators. Modal shift from private to public transport.

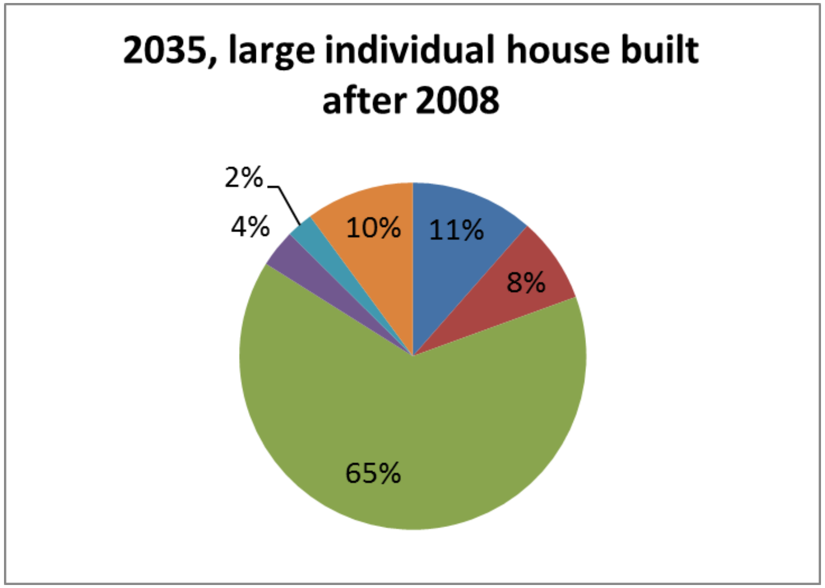
4. Part 2:
Model-based Quantitative Assessment
of urban energy systems with the example of Grenoble Alpes Métropole

- Methodological overview: EnerCity model
- Model interface and scenarios
- Results

Results: Buildings – Energy consumption per end-use

- Impact of the type of housing considered





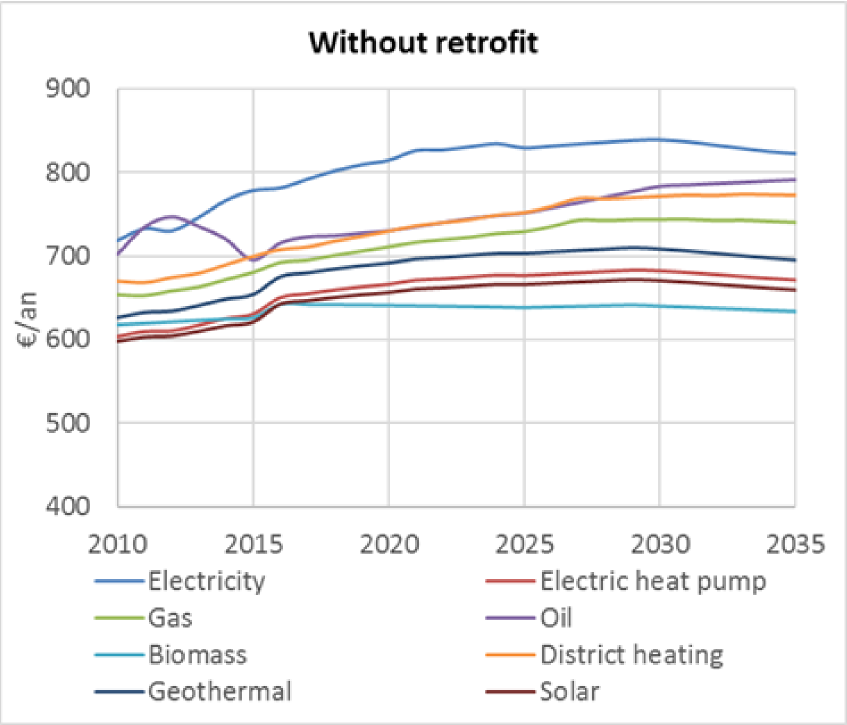
~ 1,510 kgoe

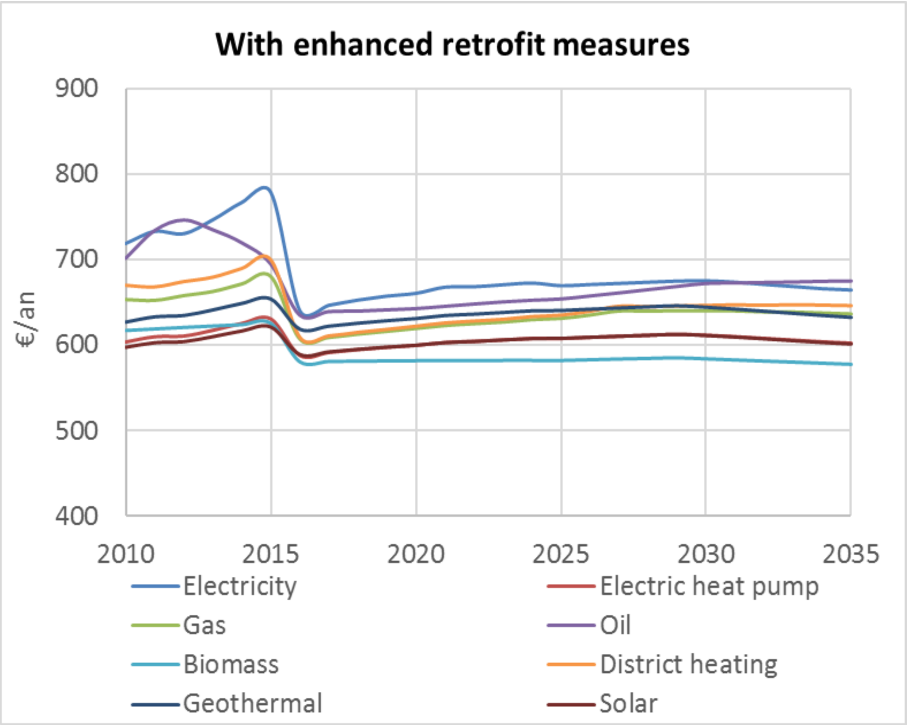
~ 1,100 kgoe

Energy consumption per energy end-use in a large flat built after 1946 ad in a large individual house built after 2008, 2035, BAU scenario

Results: Buildings – Impact of retrofit

- Up to 20% cost savings for end-users over 2015-2035 thanks to retrofit, competitiveness of the different technologies impacted

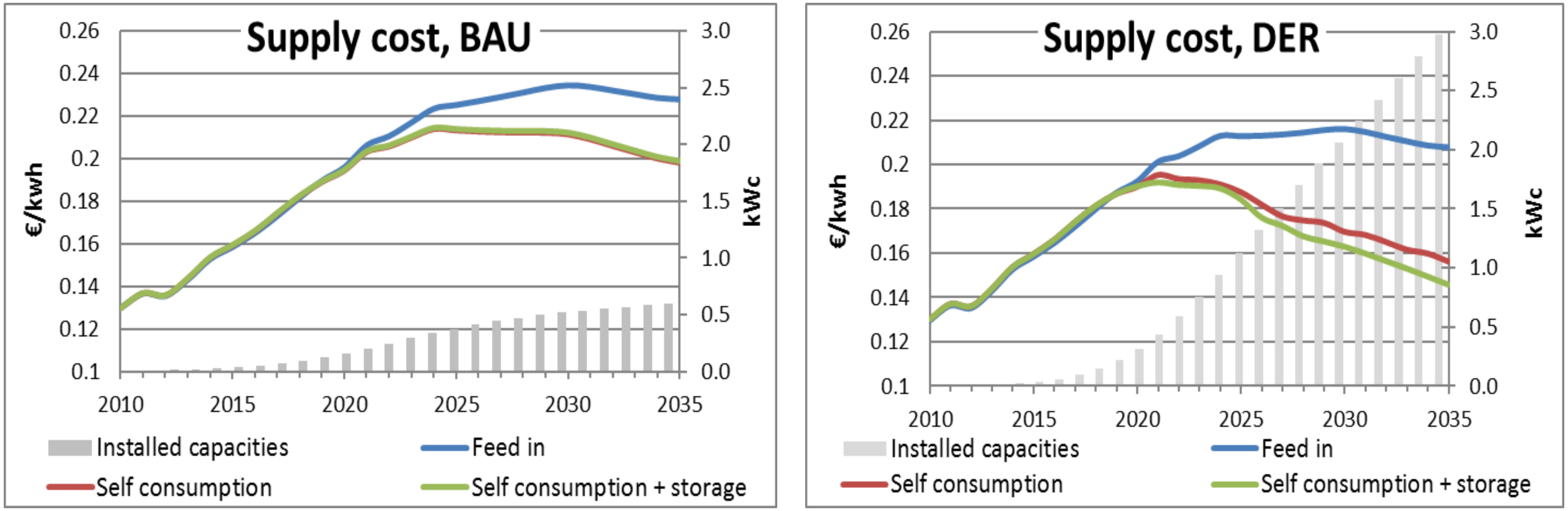




Full costs by heat equipment technology, medium-sized house built before 1946, in configurations with and without refurbishment, EE scenario

Results: Buildings – PV and storage

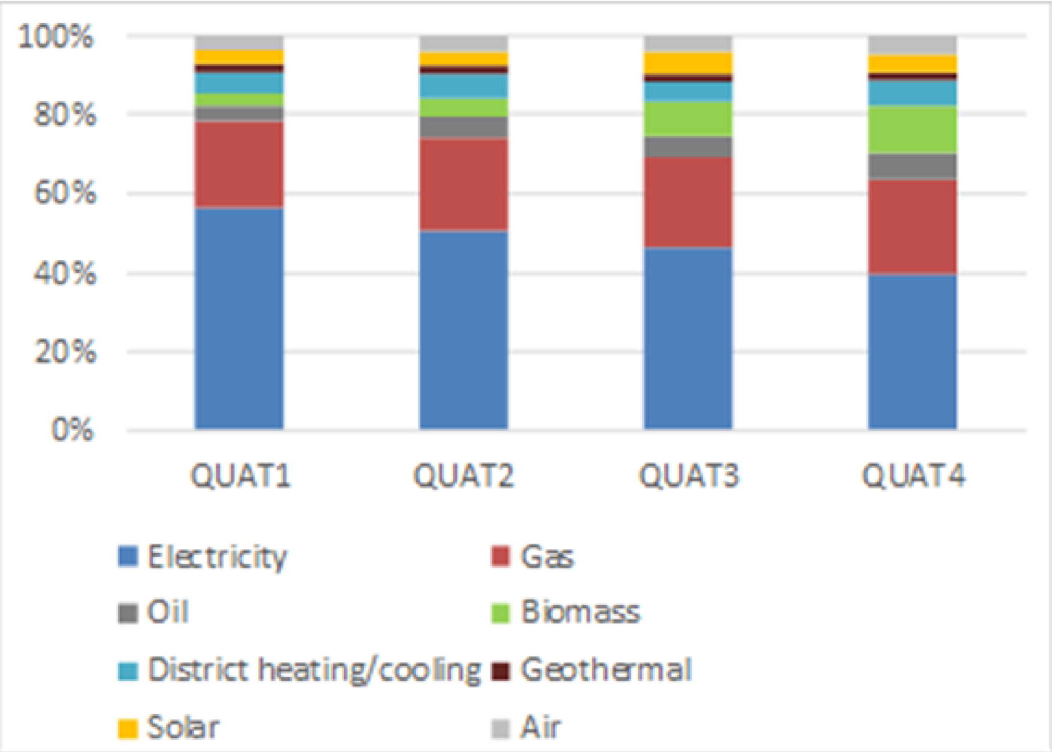
- The development of PV and storage (DER scenario) leads to lower supply costs for end-users and a growing self-sufficiency of buildings (~ 50% by 2035 vs 15% in the BAU)



PV suppy costs (€/kwh) and installed capacities (kWc) for an individual large house built before 1946, BAU and DER scenarios

Results: Districts – Impact of urban form and density

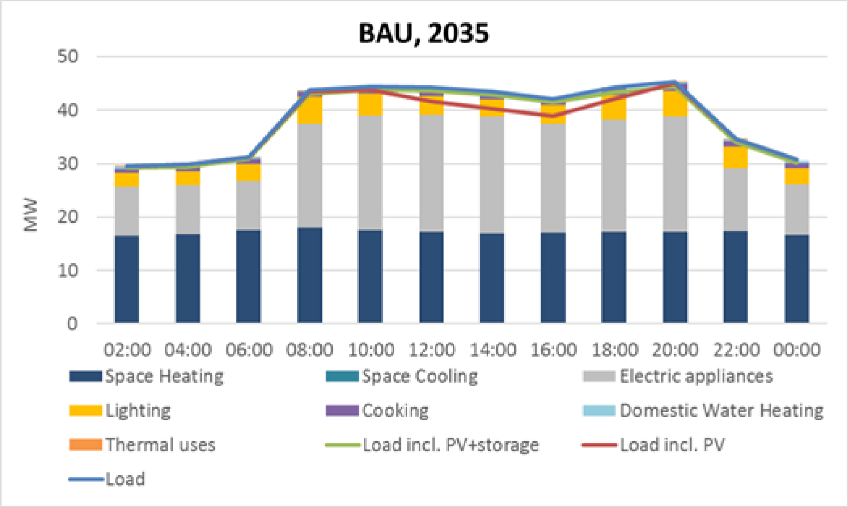
- Energy mix depending on district's characteristics

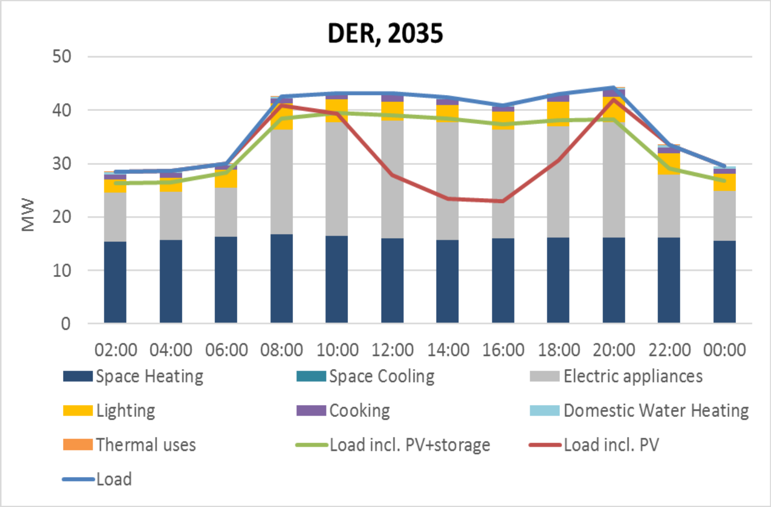


Final demand in residential and tertiary sectors, 2030, BAU

Results: Districts – Impact of PV + storage on the load curve

- Implementation of decentralised RES coupled with storage enables a significant load shift

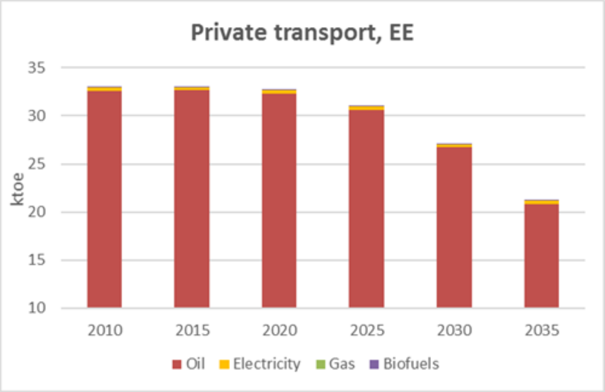


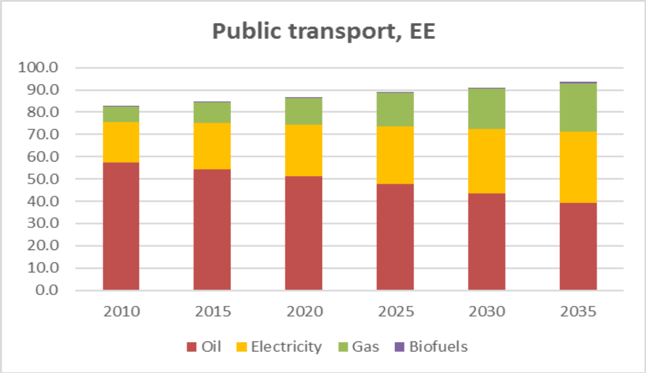


Evolution of the load curve of an inner-quarter (QUAT1) in 2035 for a given week day in winter (BAU and DER scenarios)

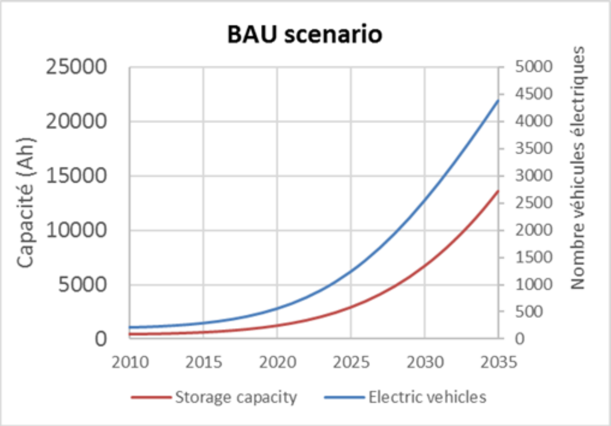
Results: City – Electric mobility and storage

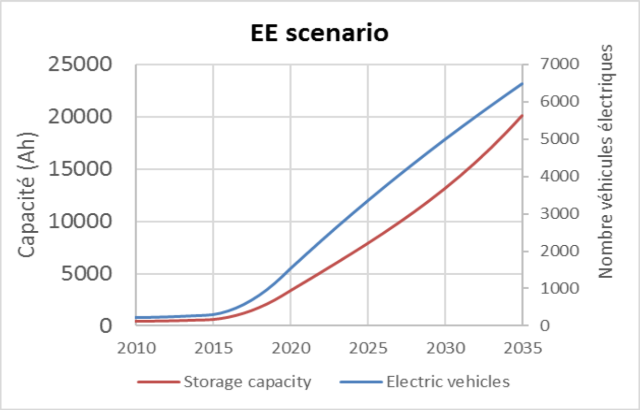
- Electrification of the sector: + 1.5 points for private transport of passengers (EE), +9 points in public transport over 2015-2035





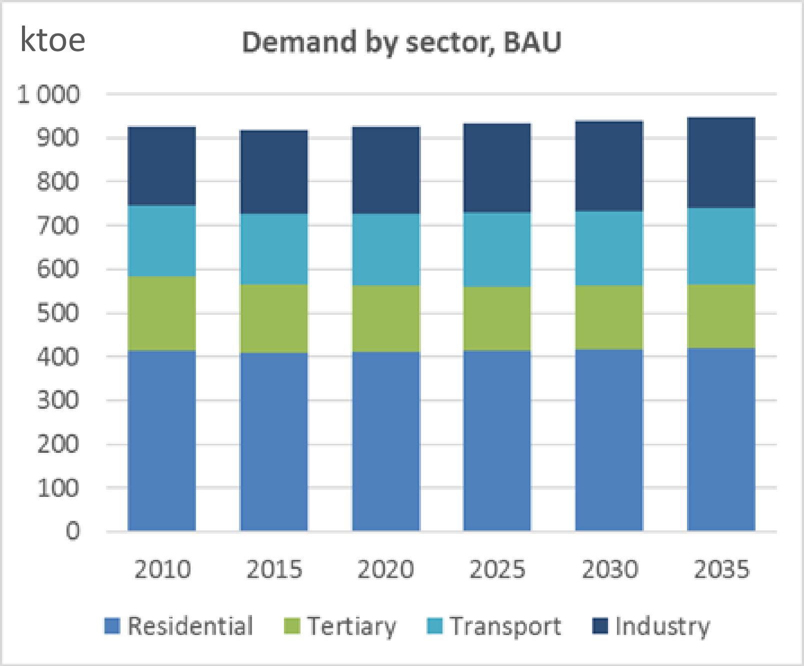
- Number of EVs increased to ~ 6000 in EE scenario by 2035: capacities > 20,000 Ah
  → Additional potential for higher flexibility of the power grid

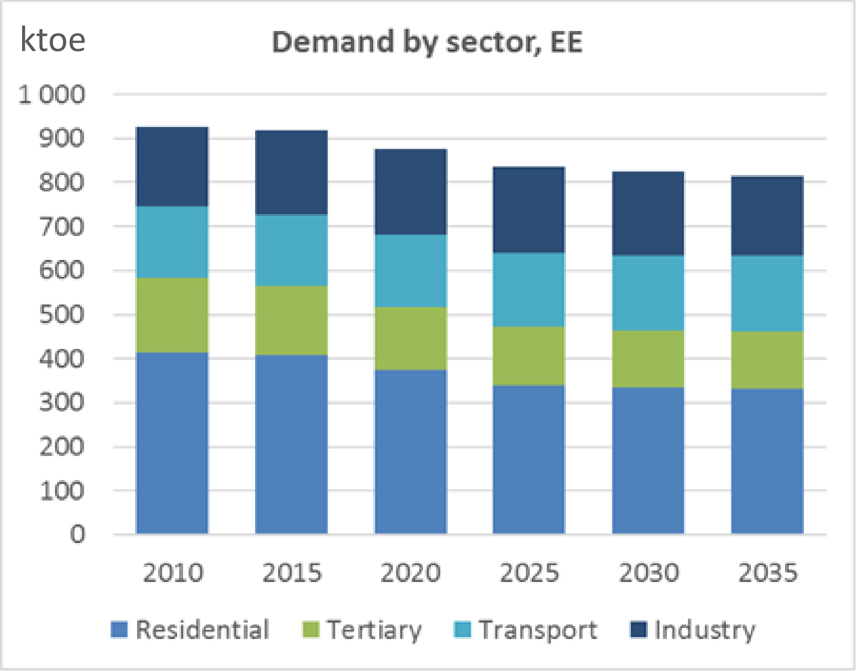




Results: City – Energy balances (1/2)

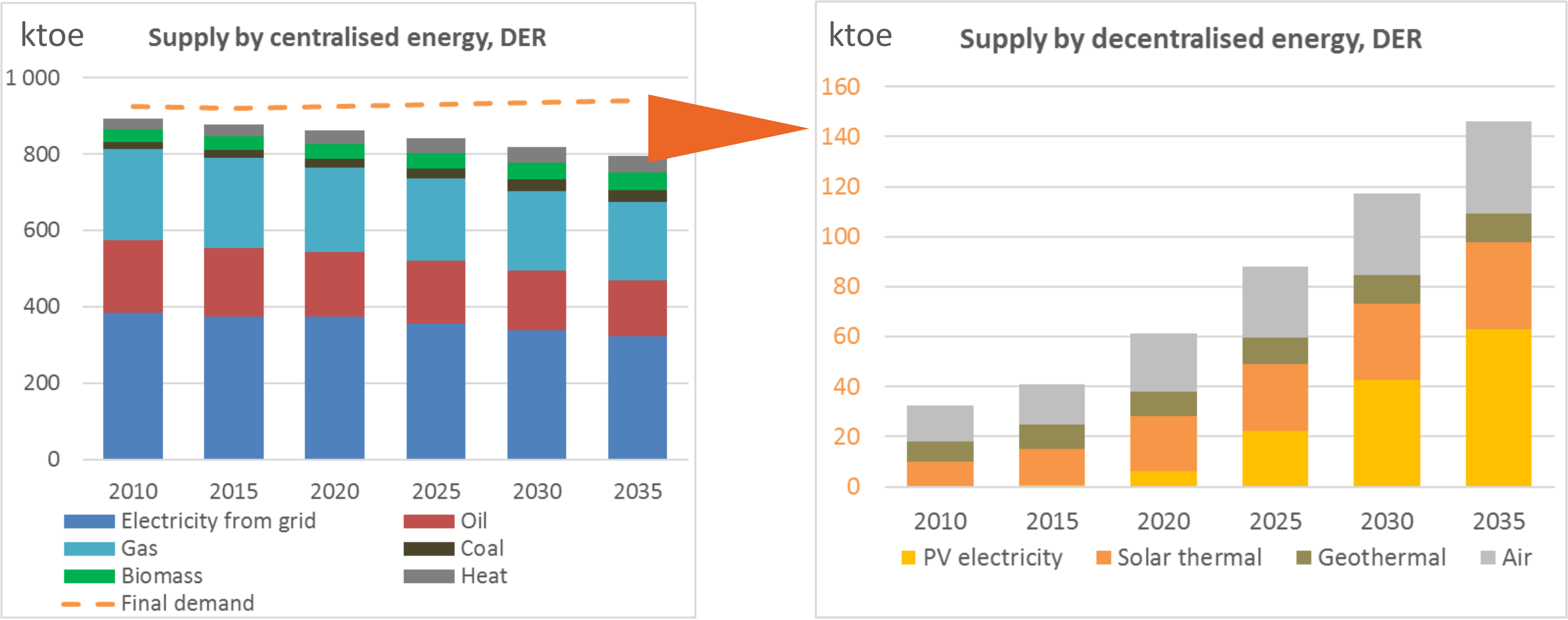
- City energy needs increase in the BAU: +3% over 2015-2035
- EE allows for a 14% energy demand reduction by 2035 vs BAU, driven by the residential sector (-20%)





Results: City – Energy balances (2/2)

- Large potential of decentralised energies and increasing role of prosumption: up to 16% of the energy supply by 2035 (DER), driven by solar (10%, PV and thermal) and heat pumps (4%)
- Growing role of district heating +35% over 2015-2035, vs +15% in BAU



Agenda

1. **About Enerdata**
2. **Introduction** to the research work
3. **Part 1: Literature Review** on current paradigms and future key challenges
4. **Part 2: Model-based Quantitative Assessment** of urban energy systems with the example of Grenoble Alpes Métropole
5. **Conclusions and Perspectives**
6. **Q/A**

5. Conclusions and Perspectives

Summary of work

Identify and assess key challenges for future urban energy systems

1. Literature review on paradigms and challenges
   - Qualitative assessment of ongoing and future challenges/solutions
   - Two-step methodology: review of international publications with transversal approach; focus on official planning and strategy documents of 10 selected cities
   - Core topics covered: ongoing transformations, challenges and solutions
2. Model-based quantitative assessment of Grenoble Alpes Métropole addressing these challenges
   - Use of EnerCity model: multiscale modelling approach for local territories
   - Allows for deep granularity into buildings' types and districts' characteristics
   - Consideration of surrounding industry and mobility
   - Derivation of energy balances at city level

Key outcomes

- Literature outcomes
  - Necessity to address fine granularity (buildings, districts)
  - Need for multi-dimensional and integrated assessment (disciplines, energy carriers, economic sectors)
  - Sustainability evaluation requires to cover economic, technical, environment and social (energy poverty) considerations
- Scenario analysis
  - Three scenarios assessed (BAU, Energy Efficiency, Decentralised Energies)
  - Required action to manage and reduce energy demand
  - Buildings' potential for energy efficiency: around 18% by 2035 vs 2015
  - Large opportunities for decentralised means: PV with storage solutions, heat pumps, solar thermal, geothermal (up to 16% of total energy needs by 2035)

Perspectives

- Data: need for availability, quality & transparency!
  - Running such models require extensive input databases at disaggregated level (buildings)
  - Typical data: historic energy consumption by building type, by end-use, by household; equipment stock; etc.
- Perspectives for future work
  - Future role of new conversion technologies (power to heat, to gas)
  - Energy poverty in a context of sustainable cities
  - Multi-dimensional indicators for urban energy systems (traditional indicators not sufficient)
  - Emissions and climate

Contact

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Sylvain Cail

About Enerdata

Enerdata is an energy intelligence and consulting company established in 1991.
Our experts will help you tackle key energy and climate issues and make sound strategic and business decisions.
We provide research, solutions, consulting and training to key energy players worldwide.

www.enerdata.net

Enerdata

Thank you for your attention!

Back-up slides

Model – Data requirements

Statistiques des bâtiments

- typologie détaillée des bâtiments : classification en fonction du type de bâtiment (par ex. maison individuelle, accolée, bâtiment collectif, immeuble) et de l'année de construction
- pour chaque élément de la typologie précédente : secteur (résidentiel, tertiaire, industrie) ; statut (propriétaire, locataire, revenu moyen) ; pourcentage des logements vacants, surface habitable moyenne, zone climatique, nombre de ménages) ; surface disponible pour le PV, le solaire thermique, existence d'une connexion à un réseau de gaz, à un réseau de chaleur
- caractéristiques des parcs de bâtiments autonomes, le cas échéant

Statistiques des territoires

- superficie par zone
- superficie disponible pour les énergies renouvelables (biomasse, éolien)
- données météorologiques : vent et ensoleillement
- densité de population par zone

Données économiques

- coûts et volumes d'investissement sur les énergies locales
- prix des énergies locales
- aides financières des agglomérations aux clients
- valeur ajoutée et nombre d'employés par branche tertiaire et industrielle

Données énergétiques

- consommations d'électricité, de gaz, de pétrole, de biomasse et de chaleur (si disponible par usage pour le résidentiel: chauffage, cuisson, ECS etc. ; et pour le tertiaire : éclairage public, hôtels, écoles, etc.)
- niveau d'équipement décentralisé installé par type de bâtiment (PV, solaire thermique, etc.) et en agglo (biomasse, éolien, chaleur, déchets, etc.)
- distance à la ressource
- production de chaleur, cogénération, biogaz

Données de transport et mobilité

- nombre de véhicules particuliers/autobus
- part moteur à combustion interne/électrique/hybride
- passagers et passagers-kilomètres par an et par mode
- km/an par voiture pour déplacements quotidiens

Model – Overview for building level

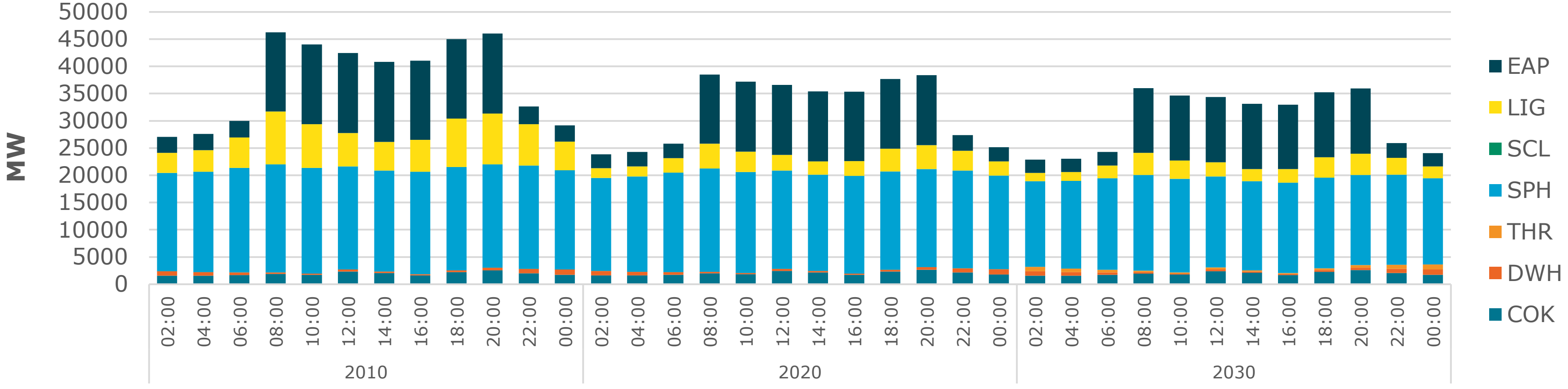
- 45 bâtiments-types en fonction
  - Du type de bâtiment (appartement, maison individuelle, maison accolée)
  - De l'année de construction (avant 1946, 1947-1975,1976-1990, 1991-2008, après 2009)
  - De la surface
- Calcul de la demande par énergie et par usage final (cuisson, éclairage, eau chaude sanitaire, chauffage, climatisation, appareils électroménagers)
- Estimation des surfaces disponibles pour l'installation de moyens de production décentralisée
- Calcul de l'offre par type d'énergie
  - Offre conventionnelle (électricité, gaz, fioul)
  - Offre décentralisée (géothermie, solaire, réseaux de chaleur)

Model – Overview for district level

- 4 quartiers-types : Centre-ville, première couronne, deuxième couronne, quartier périurbain
- Agrégation et structuration des flux énergétiques au moyen d'équations bilans
- Évaluation des coûts de rénovation et des économies d'énergie
- Dimensionnement des réseaux de chaleur et étude de leur compétitivité économique
- Simulation des courbes de charge

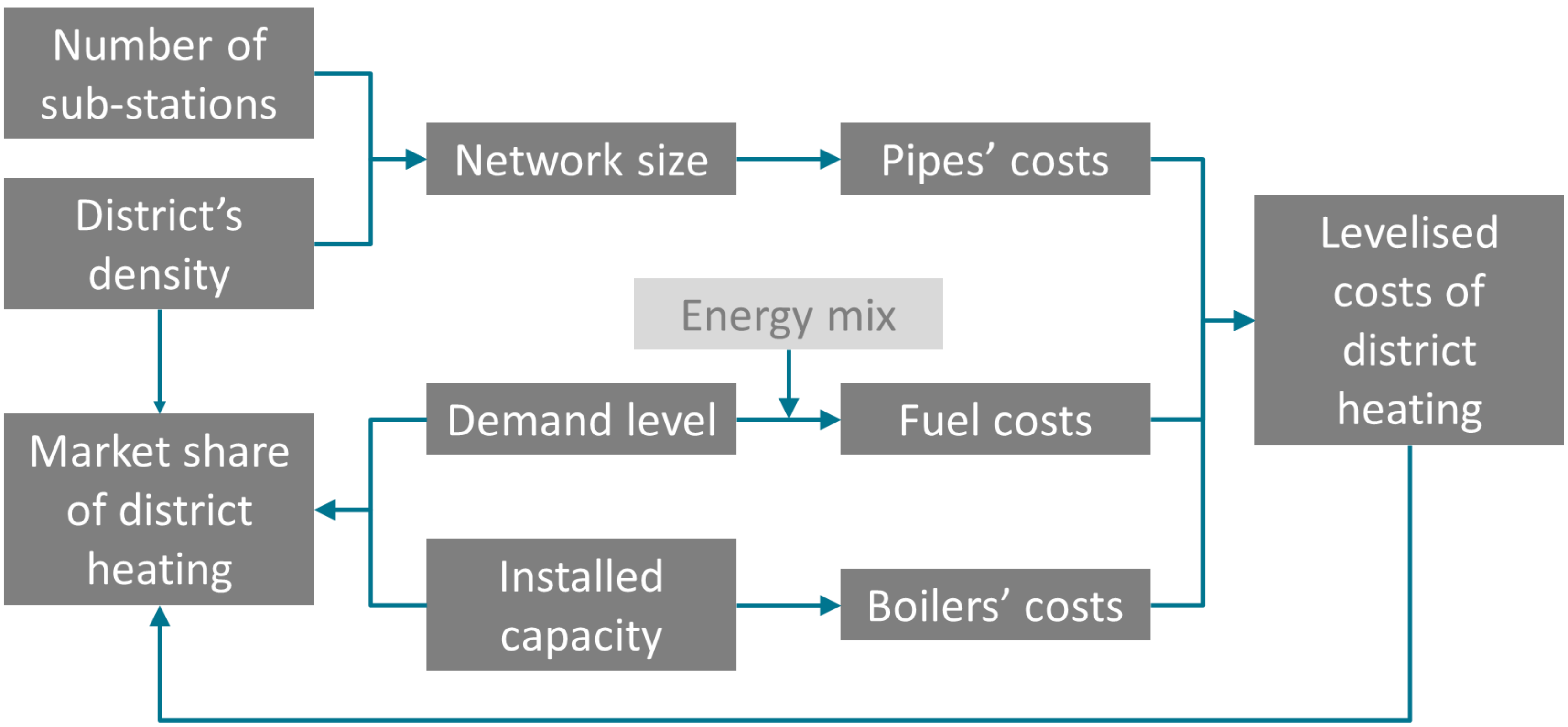
Districts: aggregation of load curves

- Aggregation all electric load called
- Consideration of « natural mutualisation » (French: foisonnement) resulting from offsets of consumption peaks



Exemplary load curve for an inner-centre district, winter working day (2010, 2020, 2030)

Model – Dimensioning of heat networks

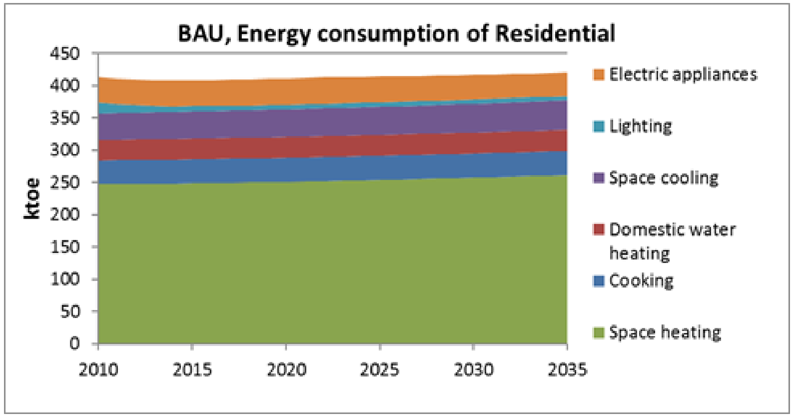


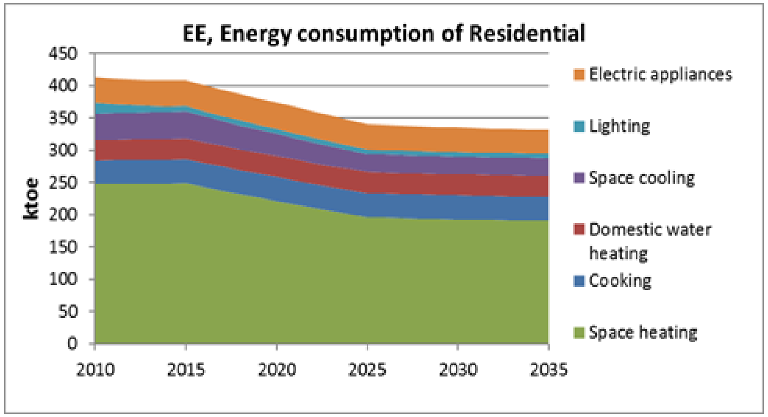
Model – Overview for city level

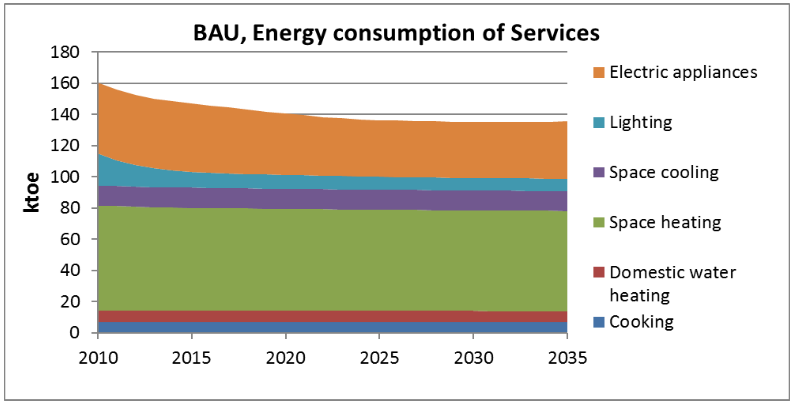
- Agrégation des flux énergétiques des quartiers (en volume et en puissance)
- Estimation de la demande en énergie induite par l'industrie et la mobilité urbaine
- Simulation de l'offre décentralisée en fonction des surfaces disponibles et les conditions météorologiques
- Bilan économique prenant en compte les investissement de la collectivité locale, les coûts de gestion locale et d'accès au réseau centralisé

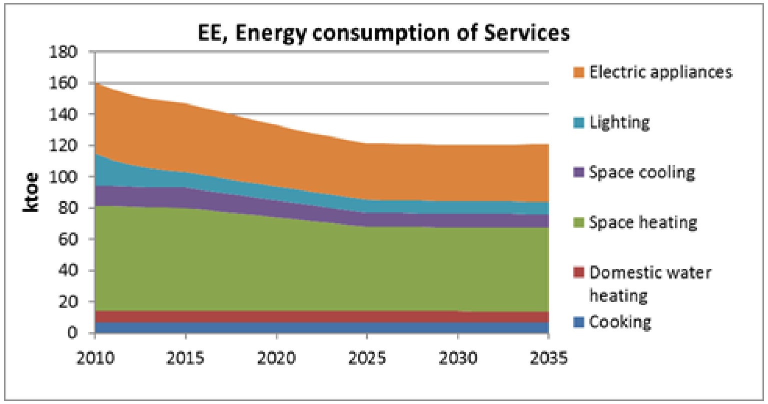
Results: Buildings – Impact and costs of energy efficiency

- EE measures lead to savings of -21% in Residential and -10% in Tertiary in 2035









Energy consumption in the residential and tertiary sectors, BAU

Literature Review – Analysis Framework

Article 7	**Urban Energy Systems - An integrated approach**
Date of publication	2013
Author(s)	J. Keirstead, N. Shah
Type of document	Book published within the BP Urban Energy Systems Project at Imperial College London
Area of expertise	Urban sustainability researchers, engineers
Central topic	Urban energy use, efficiency and technologies
Method used	Literature review, case studies and presentation of analytical tools
Summary	The book provides a multi-disciplinary analysis of urban energy systems and how energy demands in cities can be met more sustainably. It presents state-of-the-art techniques for examining urban energy systems as integrated systems of technologies, resources, and people.
Key elements brought	- Conceptualisation and definition of urban energy systems, described as “the combined processes of acquiring and using energy to satisfy the energy service demands of a given urban area” - Identification of solutions with strong energy and emissions reduction potential: buildings retrofit, distributed and district energy systems, renewables - Integrated and system-based analysis of transition in urban energy systems: transition in fuels and shift in technology (socio-technical systems transition)