# A smart and sustainable vision when assessing a smart urban renovation project: an application example

Stanislas Nösperger
EFFICACITY
14-20 Boulevard Newton
F-77420 Champs sur Marne
France
stanislas.nosperger@edf.fr

Nicolas Damesin
EFFICACITY
14-20 Boulevard Newton
F-77420 Champs sur Marne
France
n.damesin@efficacity.com

Valérie Furio
Toulouse School of Economics
Toulouse Capitole University
21 Allée de Brienne
F-31000 Toulouse
France
valerie.furio@ut-capitole.fr

Cédric Chenot
EUROPOLIA
2 Esplanade Compans Caffarelli
F-31008 Toulouse Cedex 6
France
c.chenot@europolia.fr

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## Abstract

Smart and sustainable urban districts are part of the key clues to address the challenge raised by the cities' impact on climate change. First, they foster energy mutualisation and optimal use at a district space; secondly, they enable the integration of thermal and electric renewable energy sources. However, smart district projects lead to increased up-front costs that related energy savings cannot payback alone. However, such projects generate non-energy impacts, which are very seldom taken into account in the economic assessment, although they are underlined in academic studies. This paper proposes an operational assessment of potential co-benefits of a real smart energy project for an urban district currently under renovation and extension. The project considers a partial or total integration of thermal RES in a district heating and the integration of a collective renewable power production capacity. The hereby presented assessment process focuses on four main impacts, each of them on a specific, relevant territorial scale. Two impacts are macro-economics at a regional scale: direct, indirect and induced employment impacts related to the different district energy planning scenarios; employment impacts of the reintroduction in the economy of the saved energy expenses assessed in each scenario compared with the reference scenario. Health impact is considered at the city or district scale and it is related to the implementation of energy-recovery from train braking technologies leading to the substitution of PM-emitting braking solutions by cleaner ones. Finally, the monetized $CO_2$ emissions related to energy consumptions are considered at a worldwide scale. Such operational economic assessment of non-energy benefits enlightens political decisions, which appear to be very seldom based on the sole consideration of mere financial payback from energy efficiency. However, the valuation of created or maintained jobs remains controversial and needs a subtle approach.

## Introduction

Energy efficiency investments have by and large been limited to energy-intensive industries' 'contribution to climate change mitigation' (Grubb et al., 2014). In urban projects, energy efficiency is less concerted and explicit.

However, smart and sustainable urban districts are part of the key clues to address the challenge raised by cities' impact on climate change. Currently, urban energy is too segmented (electricity, gas, heat, etc.) without any real coordination, whereas several urban activities could be mutualized (energy supply, building retrofit, etc. such as it is illustrated on Figure 1). Energy solutions and networks are oversized and renewable energy valorisation and/or recovery is not efficient. Indeed, these energy sources are not available at the same time and in the same form as the demand. In a future energy system, cities are likely to rely on the urban district scale to be energy efficient once it is an integrated system with a complete value chain with different stakeholders. This is done by the development of energy community solutions such as district heating strongly relying on renewable energy sources (RES) – based heat geothermal, biomass, heat recovery – or quite large photovoltaic facilities for self-consumption at a district level. This urban leverage effect on climate change mitigation is also crucial due to the fact that cities will stand for two third of the world population towards 2050 (UN, 2018) and since they already dominate energy demand, and by extension are responsible for a significant share of carbon emissions (64 % of global primary energy use and 70 % of the planet's carbon dioxide emissions according to (IEA, 2016)), this will only increase in the future.

However, it should be underlined that the crucial role of cities in climate change mitigation is conditioned by the ability to involve all stakeholders in an urban project and is directly linked to the energy efficiency solutions deployed.

With new large urban projects encouraged to integrate climate change mitigation through high energy performance standards or energy solutions, the impact on project costs is considerable. From the additional conception costs to all the other additions in terms of equipment, facilities and infrastructure, energy efficiency implies a considerable increase in costs when constructing new buildings and energy infrastructures (Nösperger et al., 2016). Despite this, the poor economic outlook is making it hard to justify this additional investment in the absence of a market for these ambitious projects. Yet, social and environmental cobenefits related to energy efficiency (such as fuel poverty mitigation, health improvement) are now apparent (Tirado Herrero et al., 2011; Ürge Vorsatz, 2009, IEA 2014; Nösperger & al., 2016). When assessing the economic opportunity of an urban project, how can it be ensured that the socio-environmental benefits related to improved energy efficiency are taken into account?

EFFICACITY developed an 8-stage methodology intended to assist in identifying relevant externalities of an Energy Efficiency project, determine relevant monetary values, and design suitable partnerships likely to convert them into economic flows (financial or non-financial):

1. *Phase 1. Local context identification and definition of alternative solutions (steps 1–3):*
   - Step 1: Background and overview of the initial situation (nature of the project, scope) and identification of the sets of actors involved in the project.
   - Step 2: Identification of technological and organizational solutions in energy efficiency adapted to the situation (and envisaged in the EFFICACITY relevant programs). Who do they concern and to what extent?
   - Step 3: Classification and selection of a range of solutions.
2. *Phase 2. Externalities and benefits identification, selection and monetization (steps 4–6):*
   - Step 4: Identification and selection of externalities related to selected solutions.
   - Step 5: Estimated market and non-market economic values.
   - Step 6: Arbitration of possible strategies to optimize resource allocation.
3. *Phase 3. Identification of relevant partnerships/contractual relationships and business model design (steps 7–8):*
   - Step 7: Design the business model adapted and sensitivity tests.
   - Step 8: Evaluation of the implementation conditions of the selected strategies: economic and contractual conclusions.

This approach has been applied in the frame of a new district development project in Toulouse (France) with several propositions concerning heat and power supply. This project is described in the following section.

## Project description

### CONTEXT

The flagship project for the Occitanie Region, Toulouse Euro-SudOuest (TESO) is an urban planning program, including mobility development, which aims to transform the Toulouse Matabiau train station to a main multimodal center (French acronym PEM). Since 2009, the TESO project has been gathering several institutional stakeholders such as the French State, SNCF[1], the Occitanie Region, the Haute-Garonne Department, Tisseo Collectivités[2] and Toulouse Metropole. Europolia, a public company for the local planning, is in charge of studies management and leads urban planning works.

The high-speed train line between Paris and Toulouse is planned for 2027; the PEM will be a main articulation point for the Toulouse transport network. Toulouse Metropole wants to use this opportunity to create an urban dynamic on this area with more residential, commercial and business offers by developing a new district (TESO district).

The energy transition is one of the main aims of the TESO project. Indeed, the Occitanie Region wants to become one of the first positive energy regions in France, which means to have a neutral balance between local sustainable production and consumption in 2050. This very ambitious aim is achievable only with a combination of energy savings, renewable energy production and storage as is envisioned for the TESO project.

EFFICACITY conducted preliminary studies on the energy strategy of the multimodal center and its close environment, with a team made of researchers from different organizations related to urban planning and development part of the EFFICACITY consortium.

### POTENTIAL RENEWABLE ENERGY SOURCES

A study on the potential renewable energy sources around the PEM has been made. This study includes the buildings projects for the TESO district and aims to assess production and recovery energy sources linked to the energy needs in the buildings. The study shows several thermal energy production and recovery sources:

- Geothermal sources in the underground station. Producer: Tisseo. Potential: 400 MWh/year for the heat and 200 MWh/year for the cooling.
- Geothermal sources in the underground parking lot. Producer: Future parking lot owner. Potential: 890 MWh/year for the heat and 440 MWh/year for the cooling.

1. French national railway company

2. Toulouse public transportation company

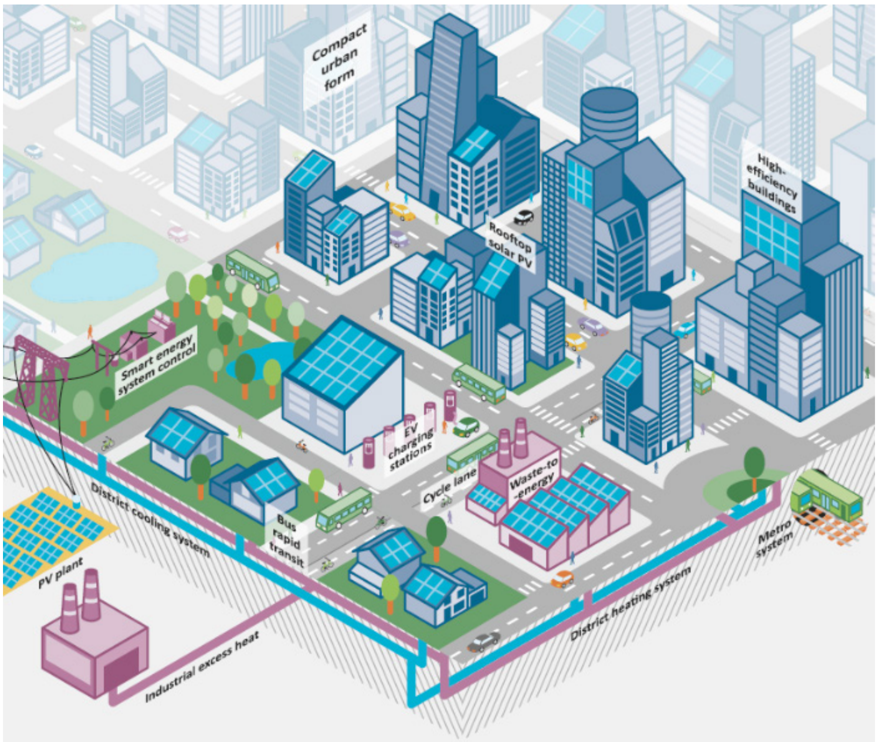


*Figure 1. Key elements of sustainable urban energy systems (IEA, 2016).*


*Figure 2. Overview of the urban district development project.*

- Calories recovery on the nearby channel. Producer: VNF. Potential: 450 MWh/year for the heat and 140 MWh/year for the cooling.

3 electric energy sources could be used on the PEM:

- Underground breaking residual energy. Producer: Tisseo. Potential: 290–365 MWh/year
- Trains breaking residual energy. Producer: SNCF. Potential: 770–1740 MWh/year
- Solar energy (on buildings and train lanes). Producer: SNCF G&C. Potential: 1200–1600 MWh/year

The first conclusions of this study show that the creation of a district heating and cooling system should be favored to supply the energy needs of the TESO district ("ZAC TESO").

#### ALTERNATIVE SCENARIOS FOR THE ENERGY PLANNING

The baseline scenario is a business as usual case which would be planned without any effort on renewable or recovery energy. There is no district heating or cooling system or renewable energy production in the area.

In scenario 1, the local energy production is used in a district heating and cooling system which is a temperate network (~20 °C) only on the PEM perimeter. For the electricity, this scenario integrates some autoconsumption with some solar energy producers able to use their own production or inject into the public network. Business as usual scenario still applies to the TESO district.

In scenario 2, the local energy production is valorized in a district heating and cooling system, which is a temperate network (~20 °C) on the PEM and TESO district perimeters. For the electricity, there is a collective autoconsumption which means a mutualization between several producers and consumers. The sources for this electricity are solar energy and breaking energy recovery from trains.

An energy-needs estimation has been done for all the buildings and systems connected to the temperate network in the aim to size the solutions used in each scenario (EFFICACITY, 2018). The urban planning for the TESO district is spread between 2020 and 2040. Therefore, the energy solutions planning will be gradually developed.

#### TECHNICAL AND ECONOMIC DATA

Table 1 sums up the relevant technical and economic data related to the different scenarios described in the previous section.

Overall investment costs take into account replacement costs, which could occur over the 2020–2050 period. These replacement cost calculations rely on a discount rate of 4.5 % in accordance with the official prescription for cost benefit analysis or public investments (Quinet, 2013).

## Assessment methodology

The co-benefits selected for the socio-economic analysis are based on the three objectives of sustainable development and are listed here:

- *Impact on employment*: the jobs mobilized as a result of the energy transition investments in each scenario (directly and indirectly); these do not only concern the investment phase and are not reduced to the strict scope of the technologies mobilized;
- *Health impacts*: the health impact of the development of brake energy recovery through the reduction of particulate matter (PL) emissions and $NO_X$ emissions through conventional boiler substitution;
- *Climate change mitigation:* contribution to climate change mitigation by reducing $CO_2$ emissions.

#### IMPACT ON EMPLOYMENT

The impact assessment of the different scenarios on employment must be understood in the sense of mobilised jobs, meaning work force needed, rather than net job creation in relation to the existing situation. Different types of jobs will be distinguished:

- Direct jobs, directly related to the manufacturing, installation and maintenance of equipment.
- Indirect jobs, linked to the branches of activity mobilised by previous actions (e.g. supplier chain).
- Induced jobs, created by additional consumer spending resulting from the creation of income from direct and indirect jobs (economic circuit).

In addition, it was necessary to assess the job loss due to the partial substitution of one energy sector by another (e.g. job loss in the historical energy sector such as nuclear power). This approach has been used by (Quirion, 2013).

It is necessary to specify the geographical scope used to assess the employment impact. The choice was made on the scale of the Occitanie region to illustrate the spinoffs, exchanges and solidarity between the metropolis and its hinterland.

The approach used to assess the employment impacts is as follows:

1. The technical solutions used in the different scenarios are identified, as well as the actors of the territory involved in their manufacture, installation and maintenance. Only actors at the regional level will be taken into account.
2. Quantification of activities in terms of sectoral added value. Thereafter, this value added is converted into full-time sectoral equivalent. Quirion (2013) provides for example such rates. This step thus makes it possible to value the direct jobs resulting from the different scenarios.
3. Use of input/output tables (also named Leontieff table) to assess the added value of the activities of the other branches mobilised by the activities of points 1 and 2. Thereafter, a conversion to full-time equivalent (FTE) will be carried out. This step thus makes it possible to value the indirect jobs resulting from the different scenarios.
4. The negative impact of replacing historical energy solutions with renewable and local solutions will also be assessed, in line with the approach taken by Quirion (op. cit.) or Lorenzon (2016). Following this step, a net impact in terms of jobs and added value can be proposed.
5. On the basis of the value added impact obtained in point 4, it will be possible to make a first estimate of the change in income (on the basis of sectorial or overall salary/value added ratios). An assumption on the average propensity of households to consume will be made to obtain an impact in terms of changes in consumer spending. Of course, only part of this consumption will be carried out at the territorial scale: a ratio of local consumption share will then be proposed and retained. This local consumption will in turn be converted into induced jobs. We will focus on this first impact loop; as ADEME (2018) points out, a more rigorous estimation of induced employment would require the use of complex general equilibrium models, going well beyond the scope of this analysis.

The deployment of steps 1 to 4 was carried out using the TETE® tool developed by ADEME and the *Réseau Action Climat* Organization (Climate Action Network) (ADEME, 2018). It makes it possible to evaluate the employment benefits of an energy transition program according to the technical solutions adopted and on a given territorial scale (from the national territory to the municipality). This part estimates direct and investment-induced employment. We use the principle of the input-output table to analyze the creation and destruction of jobs in the industries affected by these actions. TETE® takes into account the data from the Input-Output Table published by INSEE (French national statistic organization).

In the TETE® tool[3], the branches of activity mobilized by the investment and maintenance of a given technology (e.g. air source heat pump) were identified in advance. In addition, a co-

3. Figure 3 is a snapshot of the TETE® tool under copyright protection. Therefore, it is not directly translated by the authors. As an information: Orange line: "Outcome as involved work force expressed in full-time equivalent"; Green line: "Considered solutions for RES".

**Table 1. Technical and economic data of the considered scenarios for urban district development.**

| Systems | Reference scenario | Scenario 1 | Scenario 2 |
|---|---|---|---|
| Condensing boiler (individual and mutualized) | 3.4 MW Existing<br>0.8 MW Additional<br>*(2020 until 2040)* | 3.4 MW Existing<br>0.8 MW Additional<br>*(2020 until 2040)* | 3.4 MW Existing<br>3.7 MW Additional<br>*(2020 until 2040)* |
| Cooling Units | 2.4 MW Existing | 2.4 MW Existing<br>2.6 MW Additional<br>*(2020 until 2040)* | 2.4 MW Existing<br>1.4 MW<br>Additional<br>2020 to 2040 |
| Aeraulic Heat Pumps | 0.4 MW Existing<br>13.1 MW Additional<br>*(2020 until 2040)* | 13.9 MW Additional<br>*(2020 until 2040)* | 0.4 MW Existing |
| Geothermal Heat Pumps | – | 0.8 MW Additional<br>*(2020)* | 8.8 MW Additional<br>*(2020 until 2040)* |
| Temperate network (ml) | – | 1,400<br>*(2020)* | 13,000<br>2040 to 2040 |
| Photovoltaic and electric community | – | 1.6 MWc<br>(2020) | 1.6 MWc<br>*(2020 until 2040)* |
| Breaking energy recovery | – | 2.1 MWc<br>*(2020)* | 2.1 MWc<br>*(2020)* |
| | | | |
| Overall investment cost | M€2.6 | M€9.7 | M€20.6 |
| Overall Operation costs (excl. energy) | M€3.4 | M€13.3 | M€35.4 |

| | | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Résultats : emploi local, en équivalent temps-plein (ETP)** | | | | | | | | | | | | | | |
| **total** | | **27 694** | **646** | **630** | **617** | **604** | **590** | **577** | **564** | **561** | **559** | **556** | **553** | **550** |
| | **sous-total énergies renouvelables** | **27 694** | **646** | **630** | **617** | **604** | **590** | **577** | **564** | **561** | **559** | **556** | **553** | **550** |
| | **sous-total bâtiment et réseaux de chaleur** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| | **sous-total transports** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| | **sous-total énergies fossiles** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| | **détail énergies renouvelables** | | | | | | | | | | | | | |
| | éolien terrestre | 0,00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | éolien maritime | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | PV au sol | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | PV grandes toitures | 4 553 | 356 | 342 | 329 | 318 | 306 | 294 | 282 | 281 | 280 | 278 | 277 | 275 |
| | PV petites toitures | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | chauffe-eau solaires individuels (CESI) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | chauffe-eau solaires collectifs (CESC) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | PAC géothermiques | 23 141 | 290 | 289 | 287 | 286 | 285 | 283 | 282 | 280 | 279 | 278 | 276 | 275 |
| | PAC aérothermiques | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | chauffe-eau thermodynamiques | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | petit hydraulique | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | chauffage au bois, appareils individuels | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | chauffage au bois industrie tertiaire et réseaux de cha | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | méthanisation - cogénération | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | méthanisation - injection | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

*Figure 3. Example of a display provided the TETE® tool for the assessment of the employment impact of an energy transition program.*

efficient of expenditure share allocation to "local" activity (scale of the Occitanie region in this case) is applied.

The use of the Leontief matrix identifies the potential solicitation of the 99 branches of activity expressed in euros, caused by a turnover of €1 in a given branch, and makes it possible to identify the activity generated in each of the 99 branches when an expenditure (investment or maintenance) is made in the considered technology.

Subsequently, a "local" modulation coefficient is applied to the activity of each of these branches according to their presence in the geographical area in question. In the case of installation and maintenance, a coefficient of 100 % is applied. Thereafter, a coefficient of employment content expressed in FTEs per million euros is applied to each of the 99 branches.

The employment mobilizations of each of the branches through installation and maintenance induced by a given technology on a regional scale are added together. In addition, an assumption of productivity gains (learning effect, automation, etc.) leads to a decrease in the employment content coefficient each year.

Step 5, not covered by TETE, will be carried out using INSEE, EUROSTAT and Quirion (2013) data.

It should be noted that while it is not recommended to monetize job creation in order to avoid double count (France Stratégie, 2017), EFFICACITY moderates this recommendation by suggesting that monetization could be done on the basis of an expenditure ratio of the Occitanie region for economic development related to the number of jobs created.

Concerning the expenses recorded for the various building's energy solutions and in all scenarios, the following logic will be used:

- For new buildings, the initial investment and maintenance will be taken into account. A renewal of the equipment in 2035 will be modelled.
- For existing buildings, only maintenance alone will be taken into account until 2035 and then renewal costs will also be modelled.

#### HEALTH IMPACTS

##### Braking technology substitution

Health impacts can be expected as a result of the deployment of a solution to recover braking energy from metros and trains. Indeed, this solution makes it possible to replace the mechanical braking that emits pollutants and particles by an electromagnetic braking system that is not harmful. The expected reduction in harmful emissions is expected to have a positive impact on human health that will be modelled.

The approach adopted to monetize and then agree on a valuation of the positive impacts on health is as follows:

1. Identification of emissions and particulates avoided as a result of substitution of braking technologies.
2. Quantifying the emissions and particulates avoided and the number of people involved (previously exposed). This step will be based on assumptions of time and frequency of exposure and inhalation quantities per exposure.
3. Conversion of avoided inhalation quantities into health impact using endpoint conversion ratios used in life cycle analyses (typically DALY Disability Adjusted Life Years and QALY Quality Adjusted Life Years). Weidema & al. (2013) provide an analysis of reliable sources of such ratios such as IMPACT 2000, STEPWISE or EPS.
4. Monetization of the health impact expressed in terms of lifespan (stage 3) using shadow values proposed by (Quinet, 2013).
5. The values obtained are based on theoretical modelling "one cause-one impact, all other things being equal" (*ceteris Paribus*). Actually, human health depends on many factors and it would be presumptuous to predict a positive health outcome simply by modifying the braking solution. However, this change is likely to contribute to health. Rather than a monetized value provided without discussion, it will be more appropriate to agree with the public actor on an "acceptable expenditure" for the overinvestment related to this healthier braking technology and its health contribution. The concept of "acceptable expenditure" was presented by Pasquelin (2015) and reflects the willingness of an actor to allocate a predefined part of his budget, for example, to the development of an intangible resource (such as health). Expenditure is similar to the "willingness to pay" of environmental economics, but with a less material (countable) approach to the effect avoided or encouraged. However, the values estimated in Step 4 will provide a useful basis for discussion.

Following the general methodology proposed by the ExternE study (2005) conducted by the European Commission on externalities related to the energy sector, we calculate the impact of an emission reduction on chronic mortality, sudden mortality and morbidity.

The ExternE study defines three categories of health impact:

- Chronic mortality: the impact on mortality from long-term exposure to particulate matter.
- Acute mortality: the impact on mortality from a few days of exposure to particulate matter, and therefore the impact on the short term.
- Morbidity: the impact on the deterioration of the health of the people concerned.

As the ExternE study does not provide impact data on PM2.5, the health impact assessed in this EFFICACITY study will focus only on the impact of PM10 for the metro part.

##### Reduction of $NO_X$ emissions

On another side, adverse health effects can be attributed to $NO_X$ emissions coming from gas-fired boilers (around 104 g/MWh according to Cernuschi et al, 2007). Since the advanced and full integration scenarios allow for significant reduction in gas consumption, a resulting influence on heath conditions can be monetized.

Basing on a shadow value of €0.008/g $NO_X$ (CGSP, 2014b), a decrease in monetized NXW-related health costs can be expected (up to €4,000 p.a. for the advanced scenarios and nearly €6,000 p.a. for the full integration scenario).

#### CLIMATE CHANGE MITIGATION

This effect will be analyzed on the basis of the carbon balances or by energy vector of the different scenarios carried out by the EFFICACITY Powerdis tool (dynamic multi energy simulator at district scale).

A carbon cost will be realized for each scenario based on the estimated $CO_2$ emissions and the tutelary value of $CO_2$ for the year in question. This is given by (Quinet, 2013) for the year 2013 with an annual evolution rule.

A conversion to €2018 will be made (the CFSP values being expressed in €2010).

### Outcomes and results

#### ECONOMIC DEVELOPMENT & EMPLOYMENT IMPACTS

As the baseline scenario is a business as usual scenario, it is as if there was no energy transition strategy on the PEM and the TESO District. All the systems are individual for the buildings. The power and the solutions use in this scenario have been referenced in Table 1. The amount of jobs created is maximum in 2020 with 7 FTEs because of the energy systems deployments for the PEM. It increases constantly between 2021 and 2040 with the deployments of business and residential buildings on the TESO District with an average at 4 FTEs. After 2040, maintenance activities lead to an average of 2 FTEs.

The scenario 1 implies main job creation in 2020 and 2021 because of temperate network construction. An average of 6 FTEs is estimated between 2021 and 2040 then 3 FTEs after the end

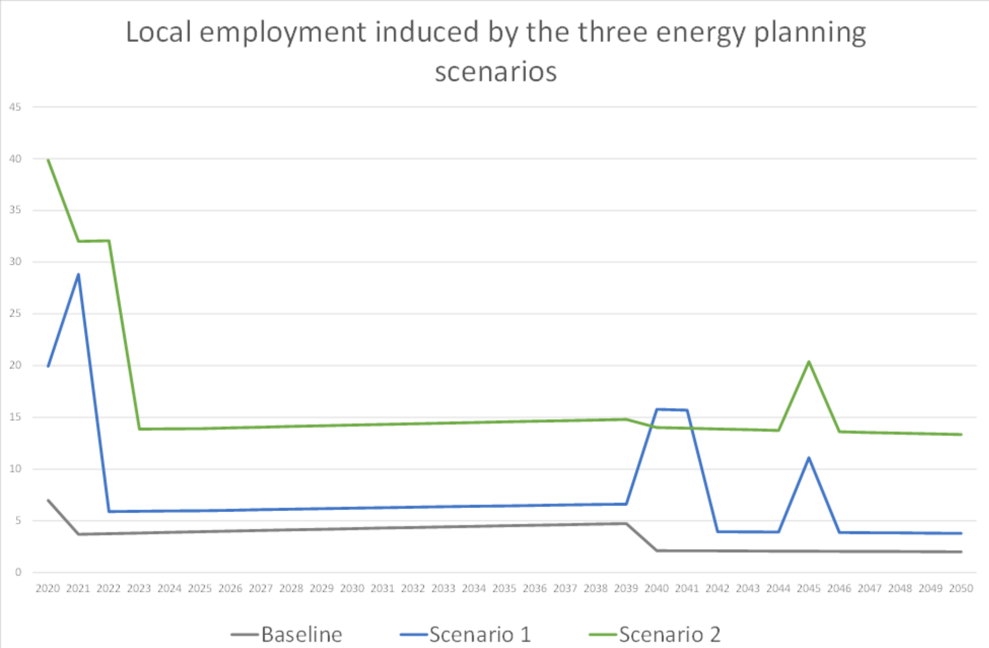


*Figure 4. Impact of the development scenarios on the local employment.*

**Table 2. Monetization of health impacts following different metro braking technologies.**

| | Health costs (€2017 / year) | | |
|---|---|---|---|
| **Health impact** | **Mechanic breaking** | **Electromagnetic breaking** | **Health benefits (€2017/year)** |
| **Chronical mortality** | 109 k€ | 65 k€ | 44 k€ |
| **Sudden mortality** | 1 k€ | <1 k€ | <1 k€ |
| **Morbidity** | 132 k€ | 79 k€ | 53 k€ |
| **Total** | 242 k€ | 145 k€ | 98 k€ |

of the TESO District construction. The 2040 peak comes from geothermal systems replacement and the 2045 peak comes from the photovoltaic system replacement.

The scenario 2 implies a constant job creation of 20 FTEs from 2021 with peaks in 2020, 2021 and 2022 because of the temperate network construction. Contrary to the other scenarios, this job creation is fairly distributed between heat and cooling network activities and renewable energy production.

### HEALTH IMPACTS

#### Subway

The main results of health benefits linked to breaking energy recovery from the subway are presented in Table 2.

The total health cost linked to the PM10 concentration because of the mechanical breaking is estimated to 2.4 M€2017 for µg/m$^3$. This result is totally coherent with the results of the Nguyen et al. (2017) study about emissions impacts on Seoul subway health users. They estimated a total cost of 382 M€2017 for 10 µg/m$^3$.

The sudden mortality costs are non-added to the total savings because they are already included in the methodology used to calculate the chronical mortality. However, it brings another precision of the economies according to each kind of mortality. The costs for the electromagnetic breaking are estimated to 0.6 M€2017 which means health benefits estimated to 1.8 M€2017/year only with the assessment of PM10 emissions.

#### Trains

For the trains use on the SNCF network, we have emission factors in *g/km train* for PM2,5 and PM10. The Quinet study (2013) supplies reference values for PM2,5 exposures but not for PM10. A similar calculation methodology used for the subway could be used for the trains for PM10, but we didn't have access to the concentrations. This calculation needs more investigation alongside SNCF or reference value creation by France Stratégie.

Therefore, the health benefits assessment for the trains is focus on the PM2,5 in this paper. The PM2,5 impacts monetarization, for a mechanic breaking leads to 300 k€2017 health cost by year. With an electromagnetic breaking these costs are estimated to be less than 100 k€2017 by year. The savings from health benefits, in a case of a change from mechanic to electromagnetic breaking, are estimated to 200 k€2017 by year only with the assessment of PM2,5 emissions.

**Table 3. GHG emissions resulting from the considered scenarios.**

| | GHG (eq $tCO_2$/y) from power use | GHG (eq $tCO_2$/y) from heat use | GHG (eq $tCO_2$/y) Overall |
|---|---|---|---|
| **Reference Scenario** | 5,000 | 2,400 | 7,400 |
| **Scenario 1** | 2,100 | 1,500 | 3,600 |
| **Scenario 2** | 2,100 | 1,000 | 3,100 |

**Table 4. Environmental assessment of the alternative energy development scenarios for the concerned districts.**

| | Climate change costs ($€_{2017}$ p.a) |
|---|---|
| **Reference Scenario** | 345 k€ |
| **Scenario 1** | 168 k€ |
| **Scenario 2** | 144 k€ |

### CLIMATE CHANGE MITIGATION

Table 3 presents the annual GHG emissions balance ($TeqCO_2$/year) for each scenario. Scenarios 1 and 2 allow a reduction in GHG emissions of 35 % and 56 % respectively compared to the reference scenario. For GHG emissions, scenario 2 is the most efficient with a significant reduction in gas consumption.

The LCA of the systems is negligible compared to other items in terms of GHG emissions.

A quick estimate of the GHG emissions of network auxiliaries (circulation pumps) showed that their impact is negligible compared to network consumption. The analysis of the LCA of the heating network shows a significant impact in the case of a wide area network (scenario 2), this is explained by the amount of work required for the construction of the network. However, this initial increase in GHG emission is compensated by the significant reduction of GHG emissions compared to the two other scenarios.

Shadow values are available for climate change impact (Quinet, 2013). The shadow value for $CO_2$ emissions is 32 $€_{2010}$/t in 2010, with an escalation rate of 4.5 % (Quinet, *op.cit.*). With an overall inflation rate of 7 % between 2010 and 2017 (INSEE, 2018), the shadow value for $CO_2$ emissions is 46.6 $€_{2017}$/t.

### OVERALL ECONOMIC ASSESSMENT (COST BENEFIT ANALYSIS)

Table 5[4] gives the outputs of the overall economic assessment for the baseline scenario and the scenario 1: investment costs, operation costs, energy related costs, life cycle costing excluding social and economic impacts and global costs including monetized socio-economic impacts. It should be underlined that for the district heating this assessment only takes into account electricity costs and not old heat prices in as much as the latter already integrates investment & operation costs (in this way, double counting is avoided).

We decided to show on the Table 5 only these two scenarios because they have comparable investment et operation costs. Indeed, the scenario 2 has a 63 M investments and operation costs (24.7 M for baseline and 31 M for scenario 1) due to a lot of backup facilities to support renewable solutions in case of high demand.

However, these back up facilities are partially justified in the scenario 2 by an insufficient potential of geothermal energy regarding the overall heat demand of the connected buildings. It should be considered to what extent this back up investment can be reduced, which raises the question of the relevant sizing and scope of the district heating. Should it be limited to the train station district ("PEM") or even to a more restricted area?

For information, the annualized social economic value/reference over 2020–2051 for the scenario 2 is -1.4 M but could be justified by the willingness of public investor to make a very ambitious project for energy transition. This result could be improved with the impact monetarization of PM2,5 for subway and PM10 for trains and less backup systems.

The economic assessment underlines that scenarios 1 is penalized by a significant increase in up-front costs which partially comes from quite inefficient (from an economic point of view) redundant investment in back-up facilities (individual condensing boilers or heat pumps at the bottom of each building).

Social and environmental benefits make it relevant to consider the "advanced scenarios" despite important up-front costs compared to the reference scenarios. However, a share of these costs is related to the settlement of the district electrical community, which turn out to have a positive cost/benefit assessment. The related positive health benefits stemming from a change in braking technologies (with strongly lower harmful PM emissions) make an additional argument for this electrical community settlement.

## Conclusions and needs for further research

The economic assessment method of a district energy development project developed by EFFICACITY and applied to the Toulouse use case helps to raise the crucial question of the relevant scope for a given district-heating plan. Monetized social & environmental non-energy benefits can shed light on the challenge of determining the economic relevance of a project with a broader point of view and can help to choose the "real" best alternative; however, they cannot be used as a "magic formula" able to justify any large RES and energy efficiency project

4. LCC = Life Cycle Cost.

Table 5. Economic assessment of the three scenarios of urban district energy development in Toulouse.

| | | Reference | Scenario 1 |
|---|---|---|---|
| Investment costs over the reference study period | € | 2.6 M | 9.7 M |
| Operation costs over the period | € | 3.5 M | 13.3 M |
| Energy costs over the period | € | 18.6 M | 17.3 M |
| Electrical community over the period | € | 0 | -9.3 M |
| **LCC exc. Externalities over the period** | **€** | 24.7 M | 31 M |
| **$CO_2$ social costs over the period** | **€** | 10.3 M | 6.3 M |
| **Health costs over the period** | **€** | 17.1 M | 7.4 M |
| **Monetized economic development impact over 2020–2050** | **€** | -1.1 M | -2.4 M |
| **Overall social & economic costs over 2020–2050** | **€** | **51.1 M** | **42.4 M** |
| **Annualized social & economic costs over 2020–2050** | **€** | **3.0 M** | **2.4 M** |
| **Social economic value/reference over 2020–2050** | **€** | **0** | **8.7 M** |
| **Annualized Social economic value/reference over 2020–2051** | **€/y** | **0** | **504 k** |

Table 6. Stakeholder of the Toulouse Matabiau district development project.

| **Player** | **Role** |
|---|---|
| State | Coordinator of the railway network |
| Occitanie Region Local Authority | Responsible for the public transportation organization |
| Garonne Department Local Authority | Management of the Toulouse Main bus Station |
| Toulouse Metropole Local Authority | Responsible for Urban development and energy-related development (at a local scale) |
| Tisseo | Management of the local public transportation |
| Europolia | Urban developer |
| SCNF Réseau | Management of the railway network |
| SNCF Mobilités | Management of the passenger and freight train traffic |
| SNCF Gares et Connexions | Owner and manager of the train stations |
| SNCF Immobilier | Owner and manager of the real-estate assets (exc. Stations) |
| ENEDIS | Power Distribution System Operator (DSO) |
| Other Railway Operators | Producer of braking-recovered energy<br>Competitor on the train transportation market |

if they turn out to be irrelevant from a technical point of view. This gives additional credibility and legitimacy to the use of global cost benefit assessment integrating social and economic impacts.

The last stages of the methodology developed by EFFICACITY deal with players game, transaction and governance challenges. These aspects have not been addressed in this paper. Indeed, they deserve further research in the frame of this district energy project. Table 6 underlines the huge number of stakeholders to take into account in the project.

The economic assessment presented in this paper will give relevant decision-making material; however the monetized impacts should be converted into real economic flow within new economic models to ensure the viability of the facilities envisaged in the "advanced scenarios". These models will rely on a formal basis (innovative partnership, contracting) but especially on informal ties (trust between actors, organizational relevance …). Otherwise, the district heating operator could either face huge financial problems or withdraw unless higher and non-optimal prices are applied to the end-customers. In any case, that would be a non-optimal socio-economic situation.

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## Disclaimer

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