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Future demand for energy services through a quantitative approach of lifestyles

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ABSTRACT

Among the tools and processes that are used to inform decisions makers on the long-term challenges raised by energy transition, numerical models are at the forefront. Whether led at the global, continental, country or local level, they help projecting the future operational conditions of our energy systems. However the possibility of addressing the sustainability challenge by changes in our lifestyles rather than technical solutions often remains outside the scope of such models whereas lifestyles contain a set of key determinants of mobility, housing, spatial planning or the organization terms of the productive sectors (industry, agriculture, services). Energy is not consumed for itself and understanding how the future demand of energy services could be framed is an important issue. This paper makes proposals to improve the consideration of lifestyles in the quantitative foresight exercises. Our methodology includes the development of a statistical model of the dynamic of changes in lifestyle patterns to derive energy service demands. The use of this model provides a more coherent framework for the formulation of lifestyle change scenarios. A set of three lifestyles anticipated for France are then designed and discussed up to 2072.

1. Introduction

Among the tools and processes that are used to inform decisions makers on the long-term challenges raised by energy transition, foresight studies are at the forefront. Indeed, due to the complexity of the energy sector, such scenarios are precious tools to identify where and when improvements may be made [1]. Whether led at the global, continental, country or local level, the prospective approach enables to rethink our relationship to energy, and to project in an unprecedented context of resource constraints and climate context [2]. Foresight studies led to address the energy and climate change issues most often requires quantitative approach in order to deal with quantitative targets such as emission levels, technological choices, investment decisions or operational constraints. The use of modelling approaches is thus common in order to simulate the energy system both on the demand and supply sides.

The modelling approaches that are available for this purpose are based on different paradigms, e.g. maximization of individual utility and respect of economic balances in the "top-down" approaches, optimization of costs under constraints in some "bottom-up" approaches. As they convey a representation of the logic of changes, these paradigms are not only neutral numerical choice. In particular they give contrasted importance to each driver of changes in energy demand: e.g. economic growth, price of energy, availability of technologies or infrastructures, public policies. Under these representations, the possibility of addressing the sustainability challenge by a change in our lifestyle rather than technical or economic solutions is often underestimated [3, for France] whereas it is intuitively acknowledged as an alternative way to reduce carbon emissions in Refs. [4,5].

This paper makes proposals to improve the consideration of lifestyles in the quantitative foresight exercises. The last few decades in developed countries and the most recent ones in emerging countries have shown us how lifestyles changes are linked to the energy consumption changes, conducting several authors to make use of this concept to describe the global background of the analysis of the demand for energy [6–8]. Lifestyles relate to our ways of "doing", "having", "using" and "displaying", our behavior and all of the related products, objects and

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infrastructures [9]. They are marked by our relationships to time, to space, to others, and to ourselves [10]. They therefore contain a set of key determinants of mobility, housing, spatial planning or the organization terms of the productive sectors (industry, agriculture, services). They thus constitute a fundamental component of direct and indirect energy consumption and greenhouse gas (GHG) emissions of a society [11–13]. However, quantifying or modelling the energy demand related to future lifestyle changes constitutes a delicate task. Indeed, lifestyle is a floating concept [14] and is hard to define [15,16]. Lifestyles are at the interface of several disciplinary fields such as economics, sociology, psycho-sociology, to name just a few.

Despite this difficulty, some quantitative approaches of lifestyles were proposed. While lifestyles are of a fundamentally non numerical nature, quantitative approaches typically focus on their expressions in measurable terms such as km driven. Examples of such attempts can be found in Refs. [11,13] who developed formal and quantitative frameworks to understand the relationship between lifestyles and energy use contributing to an alternative perspective on energy consumption. Refs [17,18] use a conceptual framework based on time-use surveys to analyze how changes in lifestyles may affect energy use. These initiatives focus on past and current lifestyles. In terms of future lifestyles, qualitative scenarios were developed in Refs. [15,19] and their consequences on greenhouse gas emissions were estimated at the household and individual levels. Finally modelling approaches of future lifestyles were proposed in Refs. [20–22] in order to analyze consequences on energy consumption and greenhouse gases emissions. These three initiatives are based on the transcription of lifestyle changes into numerical indicators which are inputs of the models. The first study used household surveys and enhanced input-output models. The second one was based on three models representing respectively the UK housing stock (simulation model containing a detailed representation of the types and fabrics of the housing stock), mobility (simulation model describing passenger and freight transport in detail) and the UK energy system (MarkAl model based on an optimization paradigm). The third one intended to include lifestyles in an Integrated Assessment Model. Even if they do not provide a representation of a whole "population and lifestyles" system with its own dynamics, these initiatives differ from classical technical-oriented approaches by an explicit consideration of lifestyle changes.

In this paper, we present a statistical model of the dynamic of changes in the consumption patterns which can be used to derive the demand for useful energy services and thus enable a more appropriate description of future demands. The model provides a representation of a "population and lifestyles" system whose behavior is simulated using patterns extracted from large households and mobility surveys. The level of demand combines demographic change and lifestyle related pattern. The advance beyond the state of the art that we proposed is the differentiation between the contributions of lifestyle evolution on one hand and technical improvement on the other. Here a drawback of classical approaches to incorporate lifestyles in foresight studies is that the consistency of the assumed changes across macroscopic indicators and with the socio-demographic context is not ensured. Comparatively, the proposed approach remains close to the societal explanatory factors. Inversely the cost of a statistical approach is the use of a larger amount of data.

This paper depicts the use of this original statistical approach by investigating three lifestyle change scenarios for France by 2072. We chose 2072 as time-horizon for three main reasons. Firstly, we wanted to go beyond the timeframe that focused most of the attention on climate and energy issues during the last decades (i.e. until 2050) and to explore the second half of the 21st century. Secondly, the long term allows us to consider radical lifestyle changes which will challenge the statistical model. While simpler methods can be appealing for medium term lifestyle changes, we believe that the long term emphasizes the systemic consistency issue. Finally 2072 is a symbolic year for sustainability as it will be a century since the book *The Limits to Growth* was commissioned by the Club of Rome [23].

Our aim is quantitative and large scale surveys are used to capture evidences of the statistical distribution of selected indicators, and to frame their long term evolution. After introducing the commonly used approaches for comparison purposes, the methodology section (2) describes the novel modelling approach we propose and the assumptions for the set of three lifestyle change scenarios for France by 2072. The result and discussion section (3) is firstly dedicated to the evolution of energy services indicators resulting from our simulations and secondly devoted to the contributions and limitations of our analysis.

2. Methods: an explicit and quantitative approach of lifestyles to build energy demand scenarios

The proposed approach aims to facilitate considering lifestyle changes as drivers of the future energy demand. But lifestyles are not totally absent from energy foresight studies. In this section, we firstly depict the way they are taken into account in current energy scenario building processes. Secondly, we present the rationale of the statistical modelling approach. Thirdly, we describe the assumptions which are necessary to build energy demand scenarios of the following section.

2.1. Preliminaries: understanding commonly used approaches to include elements of lifestyle changes in energy scenarios

We qualify as direct methods, the quantitative approaches where contrasted assumptions are formulated on the evolution of a limited set of key drivers with few causal and quantified links to lifestyles. However textual reference to lifestyles might be used to support the plausibility of the contrasted visions. The IPCC's SRES (Special Report on Emissions Scenarios) storylines provides a typical example of contextualization where coherent narratives are built to increase the relevance and utility of quantitative scenarios. Direct methods already go further by explicitly modifying quantitative indicators over time. To illustrate such approaches, we analyze in this part three energy scenarios built by three stakeholders of the French energy debate in recent years. The first one is labelled "CAS scenario" [24] and was conducted by the Strategic Analysis Center, a French governmental institution. The second one called "ADEME scenario" [25] was built by the French Environment and Energy Management Agency. The third one called "Negawatt scenario" [26] was built by a non-governmental organization in order to propose a vision for a 100% renewable energy by 2050. The time horizon for these three studies was limited to 2050. The two common energy service drivers of interest here are the total housing surface area and the total distance travelled.

Housing surface area is a key explanatory factor of service demands for heating, lighting and cooling. Table 1 reports the assumptions made for the three former foresight exercises. In the "CAS scenario", the total surface area is disaggregated in surface area per person on one hand and population size - which is a clear driver of the housing demand - in the other hand. The assumption of population size is imported from a projection of the National Institute of Statistics and Economic Studies, and the effectively discussed parameter is the surface area per person. In the other foresight exercises, three factors - which are linked to the total

Table 1
Assumptions leading the total housing surface area for the three scenarios. The shaded cells show indicators which have been the subject of assumptions.

	2010	2050 "CAS scenario"	2050 "ADEME scenario"	2050 "Negawatt scenario"
Population size relative to 2010	1	1,13	1,18	1,15
Size of household	2,25	–	2,05	2,20
Surface area of new buildings	131 m² per house 73 m² per apartment	–	Stable per type	Stable per type
Percentage of houses in new buildings	60%	–	Decreases until 40% in 2050	Decreases until 20% in 2050
Surface area per person (m²)	39,4	43,4	–	40,9 *(resulting from other assumptions)*
Total housing surface area relative to 2010	**1**	**1,24**	**1,37**	**1,19**

surface area through a mathematical relationship - are considered: the size of household, the surface area of the new building and the type of dwelling. This more disaggregated representation allows scenario developers to make differentiate assumptions on the size of household which is a much documented indicator, and on the house stock. Hence strong trends such as the surface area of new apartments that has been stagnant for 25 years and assumptions on factors which are more or less linked to public policy (urban sprawl control policy) can be translated in shares of the building stock.

The distance travelled is similarly a key determinant of the energy service demand in the transport sector. Analogically to the housing demand, building a scenario on this dimension involves either an assumption directly on passengers.kilometers travelled, or to disaggregate it into several factors. The previous foresight exercises used this last option (Table 2). In the "ADEME scenario", two indicators are distinguished: individual mobility and population size. A set of qualitative factors are invoked to define the assumption of individual mobility (decrease of 20%), e.g. teleworking, urban organization, population ageing. The same type of approach is used in the other examples, with a more disaggregated system, distinguishing especially short and long distance mobility.

These examples are described as illustrations of a possible inclusion of a lifestyle dimension in energy demand scenarios using direct methods and essentially qualitative links. The process begins by identifying key indicators used to assess the energy services demand, and if necessary disaggregates them into a few better-known indicators. These indicators are commented as a basis to select future visions: past trends, factors which influenced them in the past and which could influence them in the future. At the end, one assumption (or set of assumptions) is formulated per indicator and per scenario, resulting from choices about the relative importance of the different influencing factors, paying attention to the consistency of the scenarios and making use of expertise.

2.2. Rationale of the alternative statistical modelling approach

We propose an alternative approach to take into account lifestyle changes to build energy demand scenario. This approach is more bottom-up in its principle. It is based on a numerical representation of lifestyles whereas the direct method puts forward selected quantitative drivers and only discusses lifestyle changes as a background element. Indeed the direct methods recognized that the drivers are influenced by a set of factors, e.g. cohabitation practices, population ageing, location of the dwelling, type of dwelling (house or apartment). Yet this influence remains more qualitative or simplified in a direct approach. While future changes in the indicators are simulated, the potential interactions among the societal factors that triggered the changes are hidden.

Our proposed approach may in comparison be characterized by two objectives: (a) to place lifestyles at the heart of the scenario building process, and (b) to provide a quantitative and more functional representation of the population and its lifestyles. The first requirement involves using more descriptors associated to lifestyles as a frame to describe future coherent societies. This has the advantages to convert the energy issue into issues of everyday life, by discussing the guiding principles of lifestyles changes, e.g. changing values (for instance: importance of materialism, individualism, cooperation), changes of the technologic, economic or demographic context. The second objective allows us to simulate the behavior of a system representing the population and its practices related to lifestyles. The challenge consists in providing a quantitative representation of the population and its lifestyles while these lifestyles relate to both qualitative and quantitative dimensions and to both conceptual and practical dimensions. They are multifaceted but they have a visible resultant in individual and collective practices. Hence the proposed approach consists in apprehending lifestyles through joint statistical analyses of several French national surveys.

Surveys provide both a strong societal ground and a rich quantitative base to describe not only the average household but also the diversity of practices. Several authors used household national surveys in order to characterize past and current lifestyle changes. An application of national household surveys to compare differences in lifestyles between several European countries can be found in Ref. [27]. Similarly in Ref. [11], a survey is used to link energy use and lifestyle changes in the USA. Thus for our attempt to

Table 2
Considered assumptions leading the total distance travelled per the entire population for the three scenarios. The shaded cells show indicators which have been the subject of assumptions.

		2010	2050		
			CAS scenario	ADEME scenario	Negawatt scenario
Population size relative to 2010		1	1,13	1,18	1,15
Individual mobility *km.passenger per habitant, compared to 2010*	Short distance	1	1,02	–	0,80
	Long distance	1	1,65	–	0,75
	Total	1	1,35	0,80	0,79
Total distance per year (population) relative to 2010		**1**	**1,51**	**0,94**	**0,91**

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derive contrasted future lifestyles for 2072, the selected surveys give evidences of a diversity, from which we distinguish group of people with common characteristics and practices.

Five national surveys are concretely used in order to cover several dimensions of social practices: the population census [28], the Housing Survey [29], the National Transport and Travel Survey [30], the time-use survey [31] and the household budget survey [32] (note that [30,31] are not used for the simulations presented in Section 3). Most of the surveys are conducted periodically every five to ten years providing a valuable material for foresight. Each survey includes several variables and reports directly two types of information: information on individual (or household) characteristics and information on their practices. For example, the National Transport and Travel Survey household contains a set of variables describing individual daily mobility (e.g. number of trips, distance, means of transport, aim) and a set of variables describing the individual (e.g. gender, age, situation) and his or her household (e.g. size, composition, age of the household reference person). The "lifestyle system" is then basically perceived through a set of variables and on correlations between these variables. These correlations are analyzed through decision trees which allow dealing easily with a mix of numerical and categorical covariates. In our case, they are used to group individuals with relatively homogeneous practices or situations with regard to a given variable. The practices or situations of each group are then characterized by standard statistical analyses (e.g. mean, distribution). We use the RPART routines (as "Recursive PARTitioning") available in R to build the decision trees [33,34]. Appendix describes this process for three trip purposes and several social markers.

Different social mechanisms can lead to changes over time in the pattern of aggregated practices in a society. If it can be argued that there are as many original lifestyles as there are individuals, we can also identify some groups with relatively homogenous practices (e.g. age based groups, incomes based groups). So firstly, changes in the relative sizes of these different groups — all things equal otherwise — would also change the aggregate collection of lifestyles. Secondly we can outline social changes that involve changes in practices of each "group". Such changes may be progressive and may result from changes in perception of societal priorities (e.g. awareness for the environment during the last decades), or new social trends such as remote activity (e.g. teleworking, teleshopping, teleconferencing) or the development of a leisure economy. They also may be essentially disruptive and be perceived as radical changes with fast rates of adoption. They can be triggered by unexpected economic crisis reducing brutally the wealth to share in a society, or can originate from a massive spread of new forms of social practices enabled by wider access to new social networking capabilities (e.g. car ownership, Internet). The decision tree approach then allows us to explore the consequences of both types of changes in a prospective analysis [35]. Fig. 1 describes, as a basic example, two ways to introduce future lifestyle changes in the formal framework (more variables are used in scenarios of Section 3). In this example, the simulation process starts from a population clustered into groups of the same age and situation. Two variables are successively added to this initial matrix: the locations of household (dependent from age and situation) and the number of trips (dependent from the three other variables). Changes can be introduced (a) to the initial matrix or (b) to the correlations between variables, e.g. lower probability to live in rural areas at each age if urban lifestyles and benefits of the high-density areas are globally more valued. These changes will propagate until the variable of interest (number of trips per day). Therefore assumptions can be formulated directly on lifestyle factors instead of on the final mobility indicator as in classical approaches.

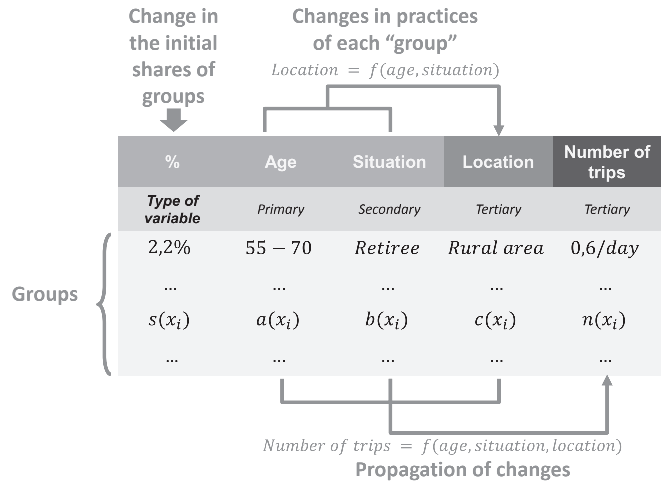

Fig. 1. Representation of the two ways of introducing lifestyle changes on a basic example.

2.3. Assumptions of the three considered lifestyle change scenarios

Here we present how the proposed quantitative approach of lifestyles can be used to build scenarios of future societal demand of energy services which could be used as input to more technology oriented modelling approaches. The challenge is to design future scenarios that have a strong internal consistency for different socio-economic or socio-demographic factors. The statistical approach provides two ways to address this challenge. Firstly, scenarios and assumptions are based on current practices, recent trends and weak signals. For example, assumptions of future cohabitation practices are based on practices of current groups of people who are a minority today. These groups are highlighted thanks to the clustering approach of our statistical model. Secondly, we explore contrasted scenarios, considering three different driving forces directly rooted in a lifestyle related framework.

Three scenarios of contrasted lifestyles evolution by 2072 for population living in France are introduced. For an easy comparison, they all converge to the same total population: from 62.8 million in 2010 to around 75.4 million in 2072 (+20% over the period). The demographic assumptions are derived from projections of the National Institute of Statistics and Economic Studies [36]. Except the migration balance which is the same for the three scenarios (+100 000 inhabitants/year), demographic growth factors may be involved at different levels resulting in contrasted age structures (Fig. 2). Each scenario is furthermore characterized by a particular set of assumptions on factors pertaining to our relation to time, space and the others (Table 3):

- The first scenario is a "current practices" scenario. The household size continues to decrease as a result of the ageing population (Fig. 3). The preference for houses continues to feed the urban sprawl (see also Fig. 4). The main structure of time use is similar to the one that is observed today where work or study especially structure the organization of the week for most people.
- The second scenario called "digital society" scenario consider a more individualistic, technological and digital society. The will of personal development drives most people to live alone, without constraints of others and results in a decrease of the desire for a child. An increased attention (and investments) to health results in a longer life expectancy (Fig. 2). To access to the

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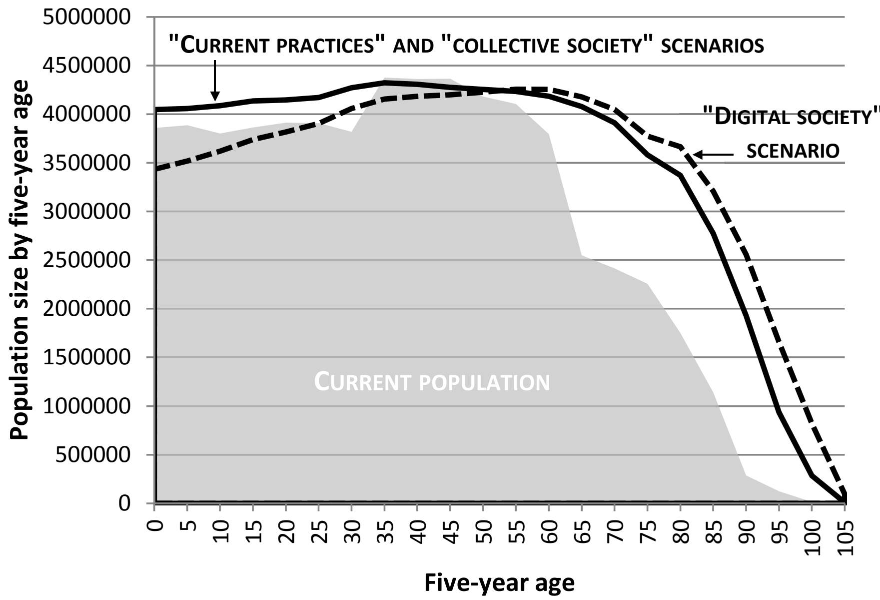

Fig. 2. Age structure in 2072 for the three scenarios.

Table 3
Summary of the hypotheses distinguishing the three scenarios.

	"Current practices" scenario	"Digital society" scenario	"Collective society" scenario
Demography (population size, age structure)	INSEE projection Central hypotheses (continuation of recent trends)	People live older, have fewer children	INSEE projection Central hypotheses (continuation of recent trends)
Household composition, relation to others	Current practices	More individual society Individual households are more frequent	More collective society Extended households and families are the norm
Location of the dwelling	Current practices (increase of peri-urbanisation)	Attraction for large urban area and densification	Attraction for urban and rural, contrary to periurban spaces
Time use	Current practices	Work even more at the heart of the organization of time	Less time and attention paid to work, more to social tasks and civic activities
Location of activities, relationship to space	Current practices	More activities carried out virtually, from home	More daily activities carried out at the district/neighborhood level (coworking space, neighborhood shops)
Population structure	Current practices	Current practices	Fewer unemployed people (share of work)
Incomes and income distribution	Current incomes	Increase of the share of high-income households	Decrease of the share of higher-income and lower-income households

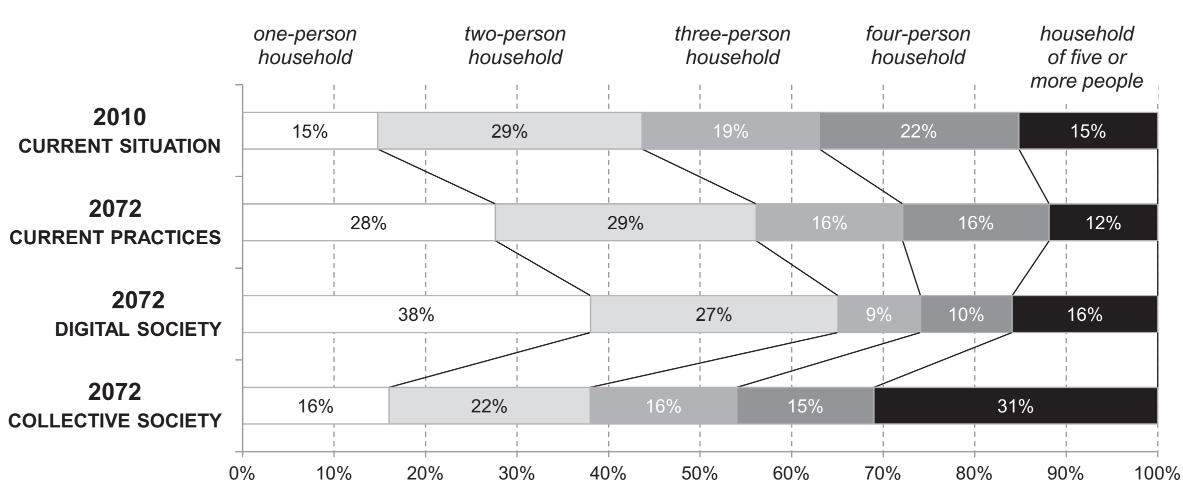

Fig. 3. Assumptions on households' size: share of the population per size of household for the three scenarios.

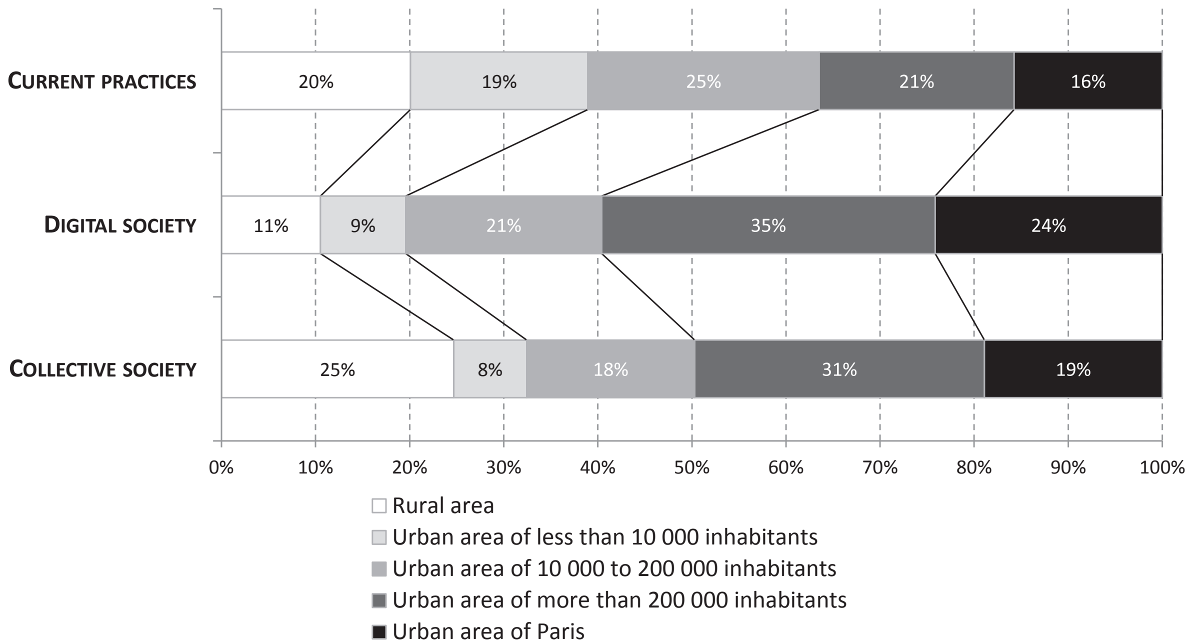

Fig. 4. Share of the population by household location in 2072 for the three scenarios.

most sought leisure and services, they live in large cities and the town centers are particularly attractive (Fig. 4). People do more activities virtually, from home (in particular social activities, work and shopping). Work is at the heart of the organization resulting in an increase of the proportion of high-income households whereas the proportion of low-income households is decreasing (Fig. 5).

- The third scenario called "collective society" scenario results from the action of different driving forces. Social ties and cooperation are placed at the heart of the society and its organization. It results in widespread forms of group housing. Urban and rural areas are popular with specific organizations whereas periurban areas are gradually abandoned or transformed (Fig. 4). More activities are carried out at the quarter level with the strengthening of neighborhood shops and the development of coworking spaces. Here the two core values of sharing and proximity are translated in a job sharing movement that is expressed as a decrease in the share of the unemployed and a modification of the revenue distribution (with a reduction of the share of higher-income and lower-income households) described by Fig. 5. This collective society is not more static one but while the number of trips for each purpose and cluster remains constant, a preference for shorter trips generates a bias towards more proximity. This is done for each population cluster at the level of the trip purpose matrix and illustrated in Tables 4 and 5. Hence in the rationale of the collective society, productive working time loses its structural role and more time and trips are devoted to local scale activities that can for instance be participatory public works, participating in local democracy, caring for elders.

The following part is dedicated to the presentation of the modelling results for these three scenarios stemming from more integrated lifestyles scenarios.

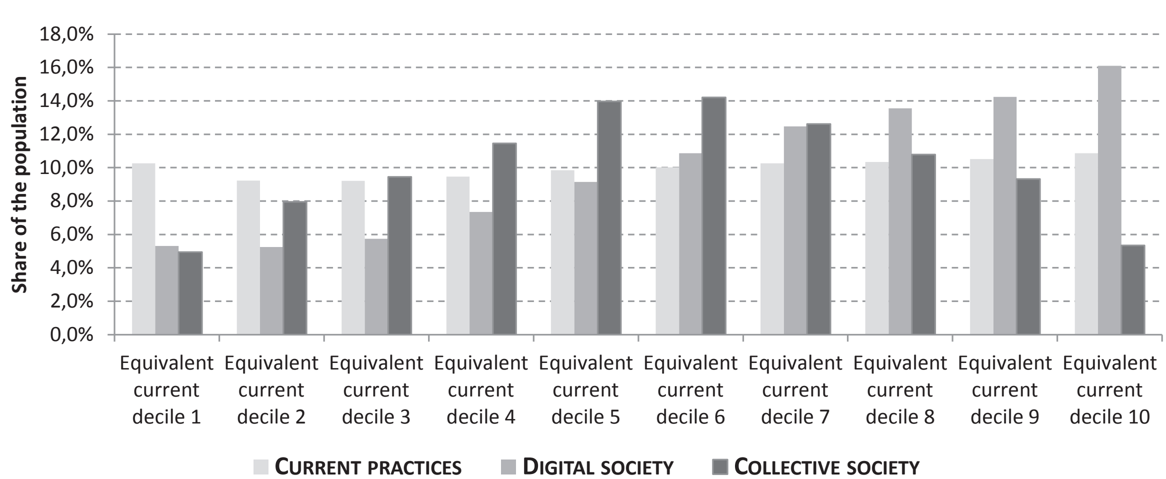

Fig. 5. Assumptions of income distribution in 2072.

Table 4
Sample of four groups extracted from the trip purpose matrixes for professional purpose (current situation and collective vision).

Trips for Professional purposes	Current situation					Situation in 2072 for collective society				
Population groups (examples)	0 to 1 km	1 to 2 km	2 to 5 km	5 to 10 km	10 km and more	0 to 1 km	1 to 2 km	2 to 5 km	5 to 10 km	10 km and more
Women who are business leaders and employees, living in rural areas belonging to a household in which the household reference person is 55 to 64 years old	15,5%	19,0%	16,1%	30,1%	19,4%	27,5%	27,0%	17,1%	21,4%	6,9%
Men who are manual workers living in the city center or Paris or cities of 5000 to 10000 inhabitants or urban areas, belonging to a household owning one car or more in which the household reference person is 45 to 49 years old	7,3%	7,2%	25,9%	32,3%	27,3%	15,6%	12,3%	33,1%	27,5%	11,6%
Men who are technicians and associate professionals living outside the city center and outside urban areas, belonging to a household in which the household reference person is 35 to 39 or 50 to 54 years old	0,7%	4,7%	9,1%	15,9%	69,7%	2,4%	12,4%	18,1%	21,0%	46,2%
Managers and higher intellectual professions living outside the city center and outside urban areas, belonging to a household in which the household reference person is 45 to 49 years old	0,9%	11,3%	11,6%	25,2%	51,1%	2,4%	24,3%	18,7%	27,1%	27,5%

Table 5
Sample of four groups extracted from the trip purpose matrixes for shopping purpose (current situation and collective vision).

Trips for shopping purposes	Current situation					Situation in 2072 for collective society				
Population groups (examples)	0 to 1 km	1 to 2 km	2 to 5 km	5 to 10 km	10 km and more	0 to 1 km	1 to 2 km	2 to 5 km	5 to 10 km	10 km and more
Business leaders, managers and higher intellectual professions, retirees living outside the city center in an urban area of less than 100 000 inhabitants, without car.	66,6%	14,5%	12,9%	3,5%	2,6%	75,8%	13,2%	8,8%	1,6%	0,6%
Business leaders, farm workers and managers living in a city center, belonging to a household owning one car and in which the household reference person is 24 years old or less or 40 years old or more.	12,8%	21,8%	20,2%	17,9%	27,3%	23,3%	31,8%	22,1%	13,0%	9,9%
Retirees living in a city center and belonging to a household owning one or two car(s), in which the household reference person is 60 to 64 years.	23,1%	18,8%	28,9%	18,3%	10,9%	35,5%	23,2%	26,7%	11,3%	3,3%
Technicians and associate professionnals, employees or manual workers of 35 to 74 years old living outside the city center and suburbs in a rural area or in an urban area of 50 0000 to 100 000 inhabitants, belonging to a household owning two cars, in which the household reference person is 25 to 34, 40 to 44 or 65 to 69 years old.	4,1%	11,1%	20,5%	14,4%	49,8%	10,1%	21,6%	30,0%	14,1%	24,2%

3. Simulation results and discussion

Meeting ambitious greenhouse gases mitigation targets will require a profound transformation of the energy system by 2072. Beyond the implementation of economic instruments, policy measures or the dissemination of clean technologies which are all necessary, lifestyles can play an important role. Lifestyles relate to aspirations that are not primarily express as energy consumption and their changes might contribute to an energy efficient society or make the challenge even greater. In this section we use the modelling approach introduced in part 2.2 to investigate future societal demands for energy services derived from three scenarios which have lifestyle changes as main driving force. Energy is not consumed for itself but as a mean to supply a demand of useful services (Table 6). Using the future lifestyle assessment model the impact of each scenario on four determinants of the future demand for energy services is quantified. More specifically the demand for housing surface area, for short distance mobility, energy demand for specific uses, and the demand for long distance mobility are discussed. The 2010 situation is depicted as a reference.

Table 6
Energy services and associated drivers.

Determinants	Energy services
Total floor area (per type of building)	Space heating, Space cooling
Composite index	Domestic hot water
	Electricity for appliance, electronics and lighting
Demand in passenger.km per distance range	Short distance mobility
Demand in passenger.km and in number of trips	Long distance mobility

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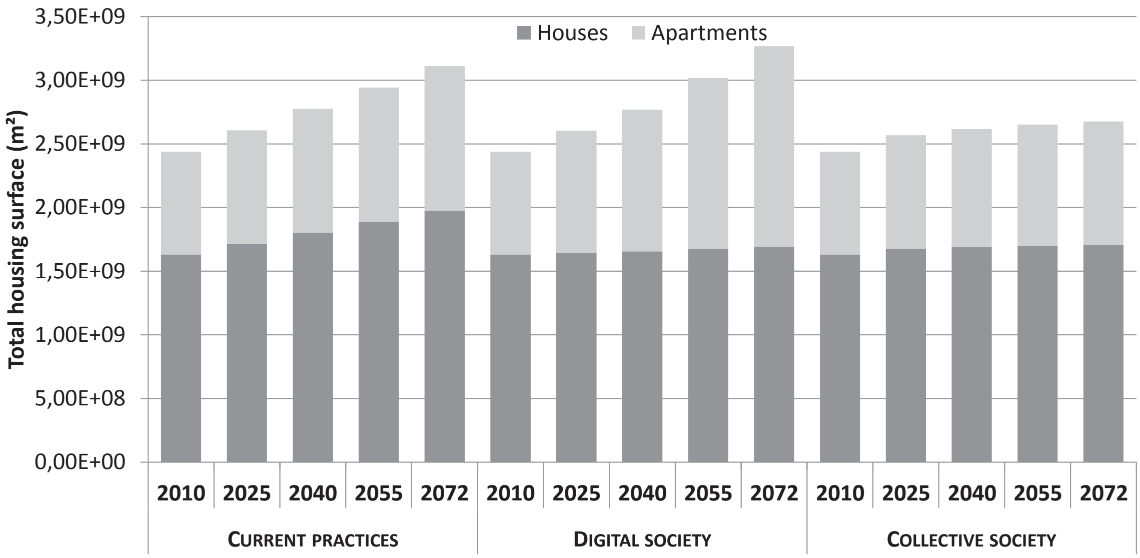

Fig. 6. Total housing surface area under the three scenarios in 2072.

3.1. *Lifestyles and future energy services demand related to housing*

The simulation results for 2072 also provide a consistent transition path towards 2072 (Fig. 6). The total housing surface area increases by 28% compared to 2010 in the "current practices" scenario and by 34% in the "digital society" scenario. When considering the "collective society" scenario, the total housing surface area to heat and to cool only increases by 10%. Two main effects influence the results: cohabitation practices (Fig. 3) and location of households (Fig. 4). The share of space is accentuated in the "collective society" scenario contributing to a decrease of 7% of the mean surface area per person. Conversely, in the "digital society" scenario, the share of space is clearly reduced contributing to the increase of 14% of the mean surface area per person whereas more people live in apartment in large cities (type of dwelling that is in mean smaller than houses in periurban areas). This simulation thus reflects the highest pressure on space and on the housing market in dense areas. In the "current practices" scenario, the two effects go in the same direction but the preference for living alone is less accentuated.

Beyond the housing surface area, additional descriptors are required in order to apprehend the final energy demand. Here the link to technical systems at the infrastructure level becomes apparent. In particular each building construction period possesses its own thermal characteristic. Given the importance of the construction period on the energy performance of buildings, the model also projects the dynamics of the housing stock that gives a finer resolution (Fig. 7) of the housing demand scenario.

The analysis of energy services demand related to housing, also comprises the demand for domestic hot water and the electricity demands for appliance, electronics and lighting. We use relative indexes built from variables available in specific surveys. This enables us to study variations due to lifestyle components, *a priori* independently of technological choices. The demand for domestic hot water is influenced by the size of

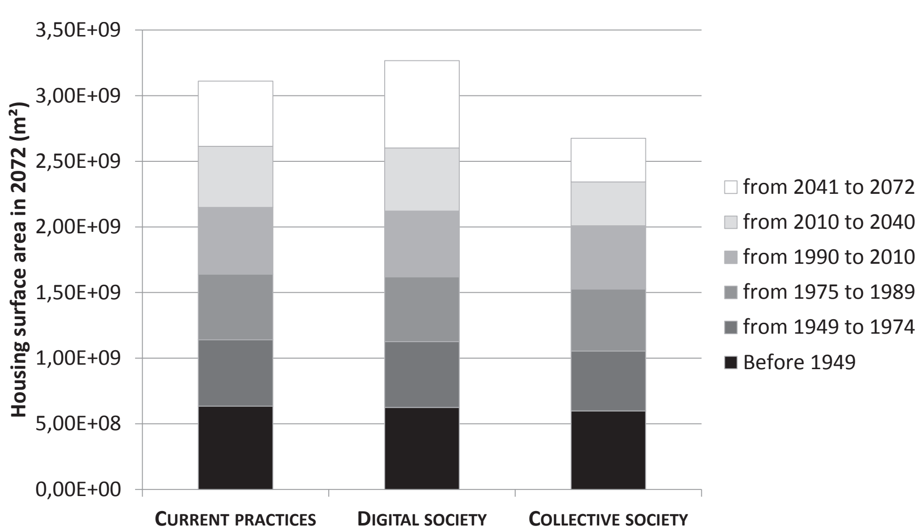

Fig. 7. Housing surface area per construction period under the three scenarios in 2072.

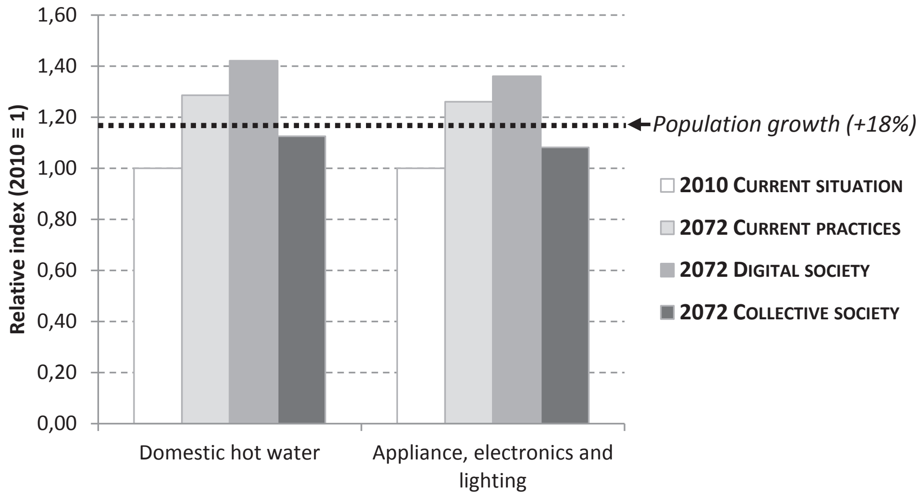

Fig. 8. Relative energy demand for "appliance, electronics and lighting" under the three scenarios in 2072.

household [37], *i.e.* by cohabitation practices. The demand for electric appliances is influenced by lifestyles through the equipment rate and the way equipment is employed. The associated electricity demand is positively impacted by the number of households, but negatively impacted by the age. It also decreases with the number of person in each household due to more possibilities to mutualize appliances. Fig. 8 depicts the consequences of the three lifestyles scenarios on energy demand for the two indexes. It can be highlighted that because of the changes in the composition of households, the demand for these two services is higher than the population growth in the "current practices" and "digital society" scenarios; whereas it is lower in the "collective society" scenario. In this paper changes in the intensity of practices were not investigated for simplification. Further scenarios could for instance explicitly introduce modified practices such as higher uses of electronic appliances by older people to account for a "generation" effect. This was left outside the scope of this paper as the related quantitative assumptions would be difficult to define based on existing sociological studies and would be too arbitrary.

3.2. Lifestyles and future mobility demand

Short and long distance mobility demands expressed in passenger.km are also influenced by the different assumptions of lifestyles. The demand for short distance mobility increases by 16% compared to 2010 under the "current practices" scenario, decreases by 11% under the "digital society" scenario and by 35% under the "collective society" scenario (Fig. 9).

In the "current practices" scenario, the demand for short distance mobility almost follows the population growth. The population ageing has the consequence to limit the increasing of the total distance travelled per year whereas the higher share of periurban population accentuates it. The "digital society" scenario consider a higher share of virtual mobility leading to a decrease of the number of trips per person, tending towards the practices of current less

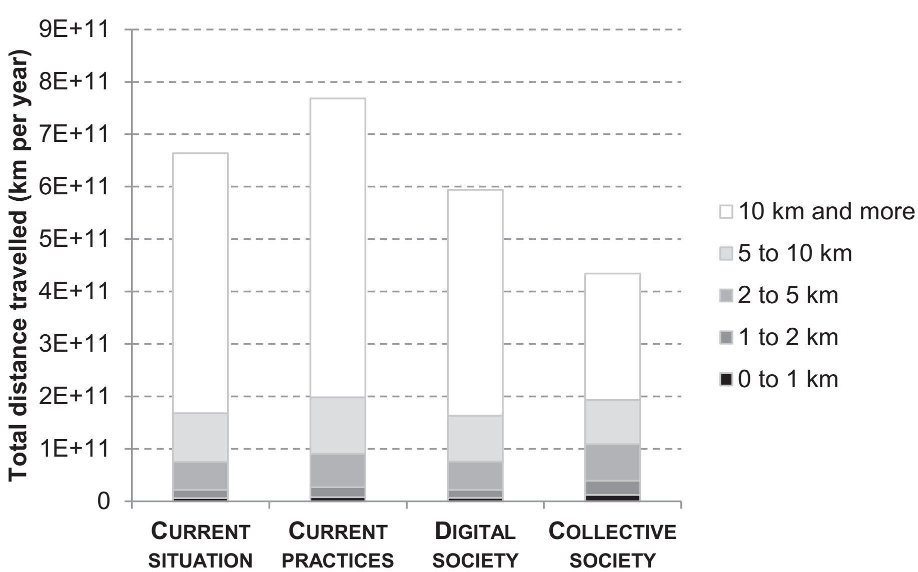

Fig. 9. Short distance mobility demand under the three scenarios in 2072.

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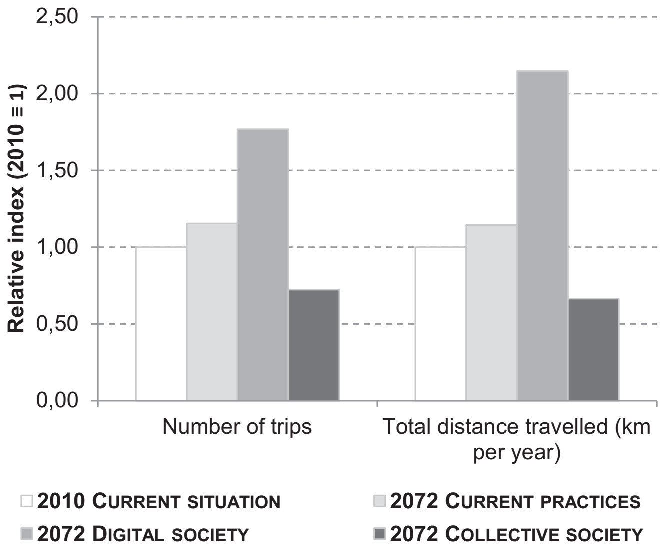

Fig. 10. Total distance travelled by the entire population for long distance mobility under the three scenarios in 2072.

mobile group of people. Combined to a more urban population where distance travelled are shorter, it results in a decrease of the total distance travelled per the entire population in spite of its growth. This result is accentuated in the "collective society" scenario but under the effect of a distinct driving force: a paradigmatic change of the mobility which is reorganized at a local level. The number of trip per person is almost the same as in the "current practices" scenario, but distance travelled per trip are shorter, tending towards the practices of current groups of people who have a local-oriented mobility.

Given this "raw" mobility demand, the modal split also involves a mix of lifestyle and infrastructure availability within the residence area. The lifestyle component will influence the relation to space and the demand for mobility per range of distance (e.g. less than 1 km, up to 5 km, see Fig. 9). In 2008, for example, 90% of trips of less than 1 km are travelled by foot whereas this share drops to 27% for trips between 1 and 2 km and to 7% for trips between 2 and 5 km. The infrastructure dimension will include the access to public transport networks and the relevant distance for each mode. By using a technical-oriented model, additional assumption of modifying the infrastructure layer and its correspondence with the different types of urban area could be investigated (higher share of public transport in medium size cities for instance). The use of the lifestyle-oriented model allow us to study more explicitly consequences of lifestyle changes by analyzing current or past practices which embody structural constraints (e.g. distance per type of area, low-mobility practices).

Finally, the simulation results also lead to contrasted projections of the future demand for long distance mobility (Fig. 10). The total distance travelled per year for the entire population increases by 14% compared to 2010 in 2072 under the "current practices" scenario, by 115% under the "digital society" scenario but decreases by 34% under the "collective society" scenario.

The main effects explaining these contrasted results are changes in incomes distribution and changes in social values. In the "current practices" scenario, these factors are not changed. The population growth and the population ageing are sufficient to explain the evolution. In the "digital society" scenario, high-income households are more numerous and travelling far away is socially valued, explaining that people tend towards practices of current high-mobile groups of people. On the contrary, high-income households are fewer in the "collective society" scenario and local social link is more socially valued, explaining that people tend towards practices of current low-mobile groups of people.

3.3. Discussion: original insights and limits of the statistical approach

In this paper, we investigate three scenarios combining several dimensions of lifestyle changes with a statistical approach. When compared to more direct methods of simulating future lifestyles using such a statistical modelling approach of changes may require quite heavy data analysis, in particular when the number of dimensions that are modified in future lifestyles is high. However there are two main benefits expected from a more explicit approach:

- The assumptions relate to factors that are more easily associated to lifestyle choices;
- The behavior of the system, the "lifestyle engine", is described as a system of groups with homogenous practices and can capture quantitatively complex feedbacks.

By distinguishing three levels of parameters – determinants of the societal demand of energy services, indicators (quantitatively linked to the determinants), and factors which are influencing indicators values –, we can illustrate the differences between the two approaches. In a direct method, the indicators are the subject of assumptions (Fig. 11). To formulate these assumptions, scenario developers may take into account qualitatively or quantitatively factors which are known to influence the indicator values. In the statistical approach, the basic factors which form the lifestyles are the subject of assumptions (Fig. 12). Determinants are then obtained by simulations using the proposed modelling approach. All the factors, indicators and determinants are linked by quantitative relationships, defining the groups and practice system.

The statistical approach can improve the scenario building process by increasing the consistency of assumptions between different sectors and parameters. This is made possible by exploiting the correlations between variables. Furthermore, the representation of the "people and lifestyles" system provides a frame to discuss or quantify our future. On one hand the lifestyles may constitute a useful reading grid to deal with future social and structural changes, giving more meaning to the described future. On the other hand, its statistical analysis framework allows a quantitative explanation of assumed changes for the future. This second framework may help to analyze past dynamics before making assumptions on the future ones. Targeted analysis on current practices which could spread may also inform the scenario building process, assuming that some of the future massive changes are already present in current society (weak signals, seeds of change).

We illustrated the relevance of the statistical approach to quantify contrasted changes in the intensity of useful services that have an impact on our energy system. Yet the boundaries of this analysis only encompasses what could be called a primary and lifestyle induced demand of service. Technology change and energy efficiency improvements could for instance reduce the gap between the "Digital" and "Collective" visions in term of effective final energy demand. Similarly a warmer climate and more frequent extreme events (heat waves or cold spells) might affect the demand for space heating and the demand for cooling. In a more complex

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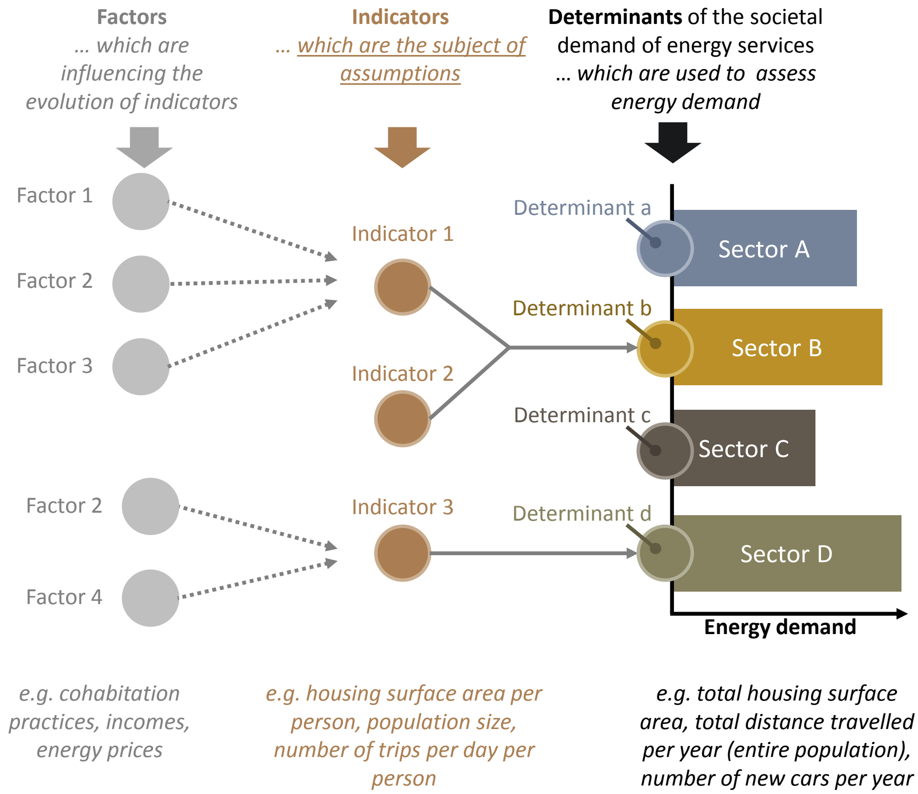

Fig. 11. Representation of the process leading to energy demand scenario under the commonly used approach.

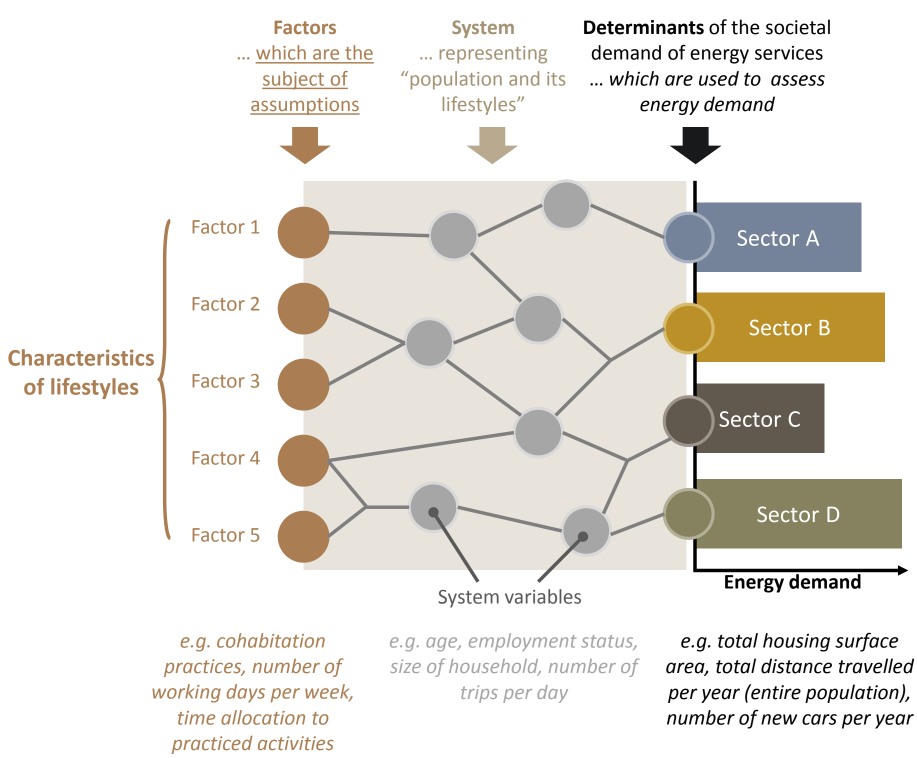

Fig. 12. Representation of the process leading to energy demand scenario under the alternative approach.

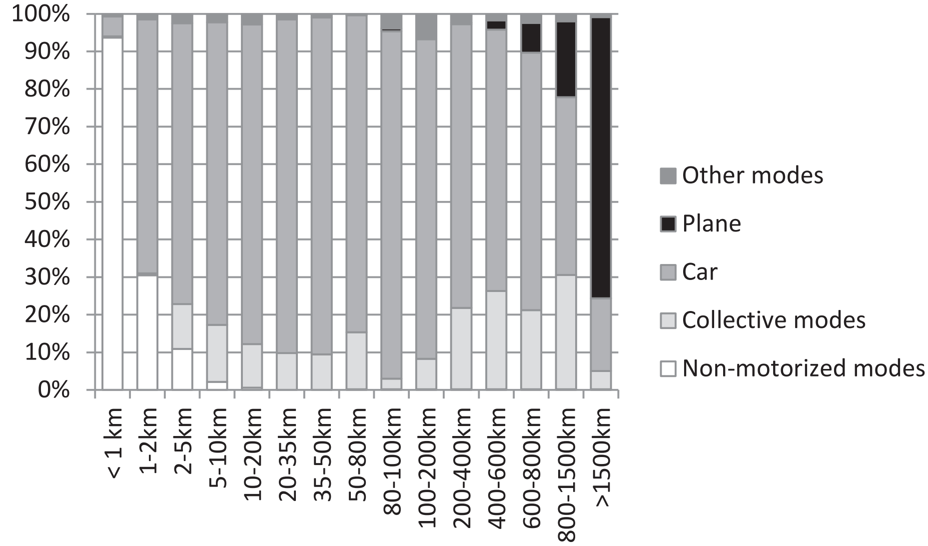

Fig. 13. Modal split per distance range in 2008 (data: National Transport and Travel Survey 2008).

interaction the effects will likely be differentiated between the different climatic zones in France. Including feedbacks on our statistical analysis is theoretically possible by introducing assumption on socio-demographic preferences for different average temperature level. Yet even for this first order interaction, the validity of a long term extrapolation up to 2072 will be hard to justify. Of course the same boundaries limitations apply for the potential effect of technology change on the final energy demand in the transport sector. On one hand, energy efficiency improvement of motorized modes could close the gap between the "Digital" and "Collective" scenarios. On the other hand, changes in infrastructural and urban system could modify the modal split per distance range (Fig. 13).

Hence the contribution of the statistical approach of lifestyles resides in its practicality as a methodology to explicitly isolate the lifestyle component and address a "grey zone" in the scenario building process.

4. Conclusion

Our lifestyles drive our energy demands through a complex combination of social, economic or demographic factors and assessing future lifestyle changes is an important dimension of any long term sustainable strategies. A key research goal is therefore to develop suitable quantitative methodologies for future demands of useful services that stems from lifestyle changes. To contribute to this objective, this paper implemented a statistical model that depicts future lifestyles and that quantifies their impacts on the demand of energy services. The model exploits the characterization of social practices provided by several national surveys in order to give a bottom-up reconstruction of lifestyles. As a result the proposed approach gives a coherent framework for the formulation of alternative demands levels by taking into account interactions between heterogeneous characteristic of lifestyles (e.g. location of households, cohabitation practices, consequences of population ageing). Compared to classical methods the societal background is very explicit, which enrich the scenario building process.

Three alternative lifestyles changes were also simulated which describe a current practices scenario, a more individualistic and digital-oriented context and a more collective way of life by 2072. The results show a great sensibility to the non-technological assumptions made and confirm the interest of the statistical approach as explicit methodology to describe future lifestyles. By promoting more collective social practices the demand for several energy services in 2072 could for instance be significantly below its 2010 level while the population increases to 72.6 million (+18%). But even in the most efficient configuration we explored, technological and policy challenges to meet ambitious greenhouse gases mitigation targets remain considerable. However, the explored scenarios only assumed a limited number of changes. Additional analyses could take into account more radical changes or include changes in practices within a group. Thanks to the use of the household budget survey in particular, further work could also consider goods and services consumption patterns, even if consequences of radical technological changes which disrupts lifestyles are very difficult to anticipate. Furthermore combining the proposed approach to other modelling approach through the concept of energy services demand opens up new perspective. In particular it can be used with technical-economic models, providing wider and more detailed energy scenarios. Using a lifestyles perspective provides a powerful reading grid to connect societal aspirations and future energy services demand. Nevertheless from a societal perspective lifestyles changes extend beyond the energy issue and should considered other goals such as social progress and well-being.

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Appendix

Table 7 provides an example of "population matrix". The three last variables of the table (number of trips per day for three purposes) were added by using three "correlation matrixes" related to these variables. These correlation matrixes are represented in the form of their decision trees by Figs. 14–16. To add a variable, each line of a population matrix is classified according to its characteristics and following the decision tree (see "group" columns in

Table 7
Population matrix after adding three variables related to number of trips per day (extract). *NB: the "group" columns inform on the decision trees-group to which each line belongs.*

Size group	Gender	Five-year age	Situation	Age of the household reference person	Socio-professional categories	Household location	Number of trips per day for … (annual means)					
							… shopping		… prof. purpose		… leisure	
variable name	*gender*	*age*	*situation*	*agehrp*	*cs8*	*location*	Group	*ntrip2*	Group	*ntrip9*	Group	*ntrip7*
109 870	Male	60	5	60	7	4	*S9*	1,284	*P1*	0,013	*L6*	0,897
109 087	Female	20	3	20	8	7	*S3*	0,821	*P1*	0,013	*L6*	0,897
108 295	Male	80	5	80	7	5	*S9*	1,284	*P1*	0,013	*L5*	0,726
107 935	Male	25	1	25	4	7	*S2*	0,637	*P4*	1,111	*L2*	0,655
107 187	Male	10	3	40	6	0	*S1*	0,429	*P1*	0,013	*L5*	0,726
106 802	Male	45	1	45	4	0	*S4*	0,819	*P7*	1,362	*L1*	0,574
105 091	Male	65	5	65	7	6	*S9*	1,284	*P1*	0,013	*L6*	0,897
104 633	Female	65	5	70	7	0	*S8*	1,082	*P1*	0,013	*L6*	0,897
104 594	Male	50	1	50	4	0	*S4*	0,819	*P7*	1,362	*L1*	0,574
103 030	Male	20	3	20	8	7	*S2*	0,637	*P1*	0,013	*L6*	0,897
102 412	Male	70	5	70	7	6	*S9*	1,284	*P1*	0,013	*L6*	0,897
102 378	Male	80	5	80	7	1	*S9*	1,284	*P1*	0,013	*L5*	0,726
102 168	Male	50	1	50	3	7	*S4*	0,819	*P4*	1,111	*L2*	0,655
101 913	Male	80	5	80	7	4	*S9*	1,284	*P1*	0,013	*L5*	0,726
100 654	Male	50	1	50	6	7	*S4*	0,819	*P4*	1,111	*L2*	0,655
98 639	Male	65	5	65	7	3	*S9*	1,284	*P1*	0,013	*L6*	0,897
98 479	Female	60	5	60	7	8	*S9*	1,284	*P1*	0,013	*L6*	0,897
97 363	Male	55	1	55	6	0	*S4*	0,819	*P7*	1,362	*L1*	0,574
96 234	Male	45	1	45	3	7	*S4*	0,819	*P4*	1,111	*L2*	0,655

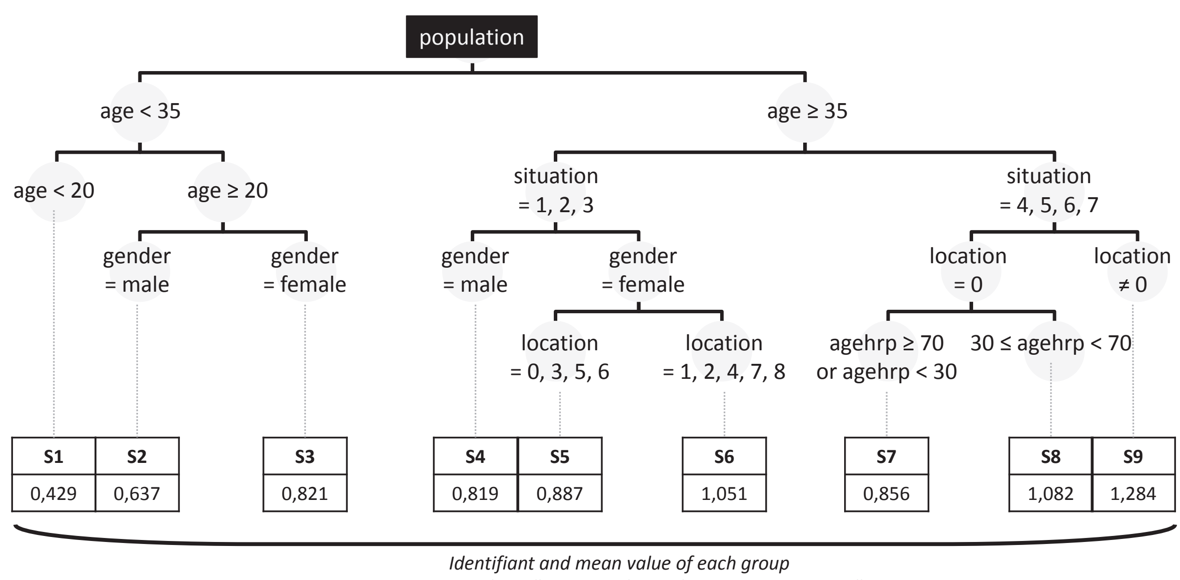

Fig. 14. Decision tree related to the "number of trips for shopping" variable.

Table 7, which is then deleted). Finally a column with the new variable is added to the population matrix with the appropriate number of trips for each line (group mean value).

Note that the meanings of the codes for the variables "situation", "location" and "socio-professional categories" is available Tables 8–10.

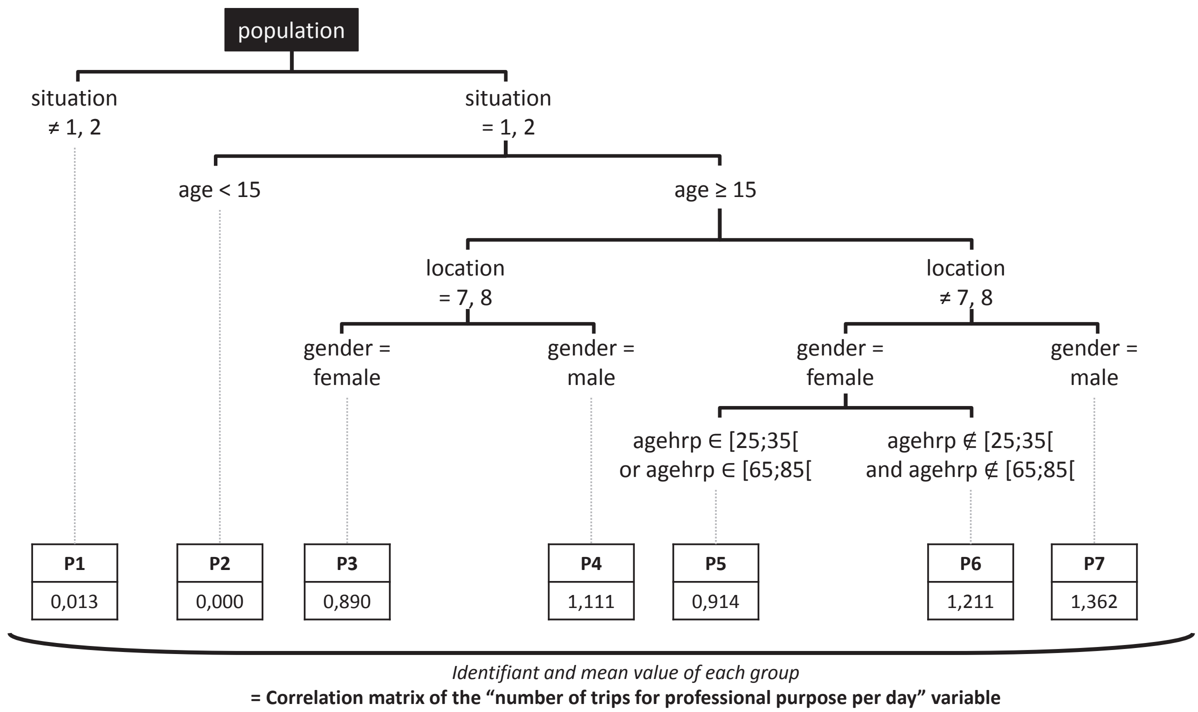

Fig. 15. Decision tree related to the "number of trips for professional purpose" variable.

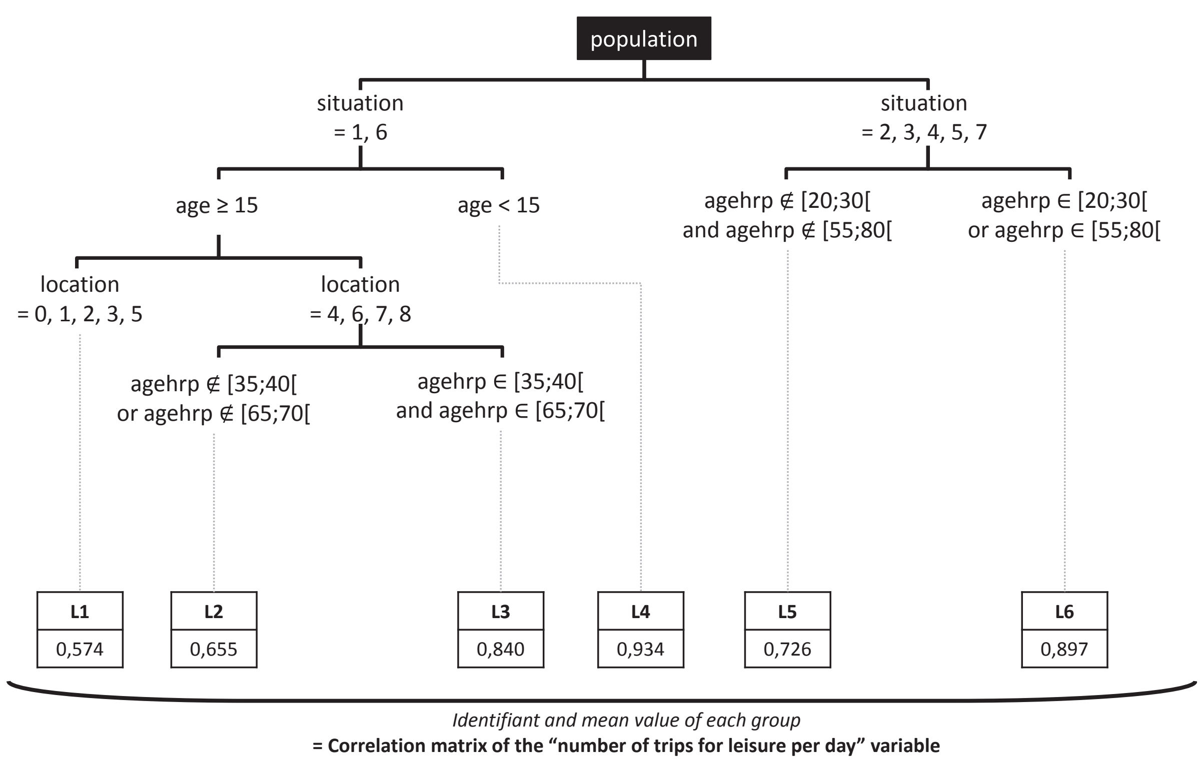

Fig. 16. Decision tree related to the "number of trips for leisure" variable.

Table 8
Meaning of situation codes.

Code	Situations
1	Active worker
2	Trainees, apprentice
3	Student
4	Unemployed
5	Retirees
6	House-husband or housewife
7	Other situations

Table 9
The nine classes of the household location variable (data: Insee, population census).

Code	Description
0	Rural municipality
1	Urban unit of less than 5000 inhabitants
2	Urban unit of 5000 to 9999 inhabitants
3	Urban unit of 10 000 to 19 999 inhabitants
4	Urban unit of 20 000 to 49 999 inhabitants
5	Urban unit of 50 000 to 99 999 inhabitants
6	Urban unit of 100 000 to 199 999 inhabitants
7	Urban unit of 200 000 to 1 999 999 inhabitants
8	Urban unit of Paris

Table 10
Meaning of socio-professional categories codes.

Code	Socio-professional categories
1	Farm workers and managers
2	Business leaders
3	Managers and higher intellectual professions
4	Technicians and associate professionals
5	Employees
6	Manual workers
7	Retirees
8	Other situations

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