Assessment of the very long term development of the needs of energy services : the VLEEM methodology

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The European Union launched two years ago an effort to develop a new energy model called Very Long Term Energy and Environmental Model (VLEEM). Special emphasis of the model is the energy development over one century, worldwide. A back-casting methodology is applied, especially to address sustainability issues. The results of the model should help the European Union to shape its energy research portfolio. This paper presents how the needs of energy services over the very long term are assessed and modelled in VLEEM. More detailed information and literature about VLEEM can be found in www.VLEEM.org .

1 New concepts for assessing energy needs on the very long term: socio-cultural functions, time-budgets and needs of energy services.

1.1 Socio-cultural functions, time-budgets and needs of energy services

Long term energy demand studies and forecasts usually rely on a prior assessment of the "needs" underlying energy demand. In the very long term, beyond 50 years, such an assessment has to be carried out so as to capture very slow changes, which may have no significant impacts on the usual time frame of the energy forecast (20-30 years), but which might become of primary importance beyond 50 years. Basic expression of life-styles and behaviours of people belong to such changes.

In VLEEM, life-styles and behaviours are captured within **"socio-cultural functions"** of individuals which refer to the basic life functions of the people, and which make sense as regard energy needs. They are assessed through their most stable, well known and measurable components over the very long term: the time budgets (day will comprise 24 h. for ever for everybody!).
Crossing practical and theoretical considerations, the 24 hours daily time budgets are eventually split into four main socio-cultural functions:

- « **food and feeding**»: time used to self-produce, pick-up, purchase, conserve and prepare the food, as well as time spent in the kitchen for all other purposes related to food;
- « **shelter and lodging** »: time used for self-building and self-maintaining the shelter, as well as time spent for all physiological (other than food) and sanitary purposes within the shelter;
- « **working for money** »: time used either to produce goods or services for selling, or time spent in paid job;
- « **self accomplishment** »: time used in all other activities dedicated to culture, religion, education, sport, communication, etc…

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Time budget allocated to **transport**, which could be accounted for within the time-budgets devoted to these four functions, is nevertheless considered separately in VLEEM.

Within each socio-cultural function, and for transport, the "needs" refer to the “**energy services**” attached to the functions, and are expressed in a manner which is specific to each energy service: for example, food conservation is an energy service attached to the function "food-feeding" and the need of food conservation means the permanent storage volume for conservation needed by a household. The needs of energy services attached to a socio-cultural function comprise both these directly expressed by individuals and those induced in the production system.
As shown by former studies (ECODEV, 2000), needs of energy services have close connections with time budgets: either directly (for example, the less time spent in the food-feeding function, the more diversified the energy services and the more intensive the needs) or indirectly (for example, the more time spent to work for money, the higher the affluence, the bigger the house and the more diversified the in-door services).

1.2 From needs of energy services to useful energy

The needs of energy services are first expressed with specific units, for example the volume of food conservation. But, to compare and aggregate these needs among themselves, and to link them to the energy demand, it is necessary to express them also in **useful energy** terms, both in quantities (GJ) and in qualities of energies required for the services. To be quantitatively relevant, this conversion in useful energy can nevertheless be done only in a precisely defined physical and technological context. For example, food conservation could mean either refrigeration, or freezing, or any other conservation technology, and the relation to useful energy depends on the technology used.

In VLEEM, the calculation of the useful energy related to the needs of energy services is **first** done on the basis of the **current technology paradigm**, i.e. the current and future set of technologies using the existing conventional energy forms, and taking place in the existing production system of equipment and appliances. This includes technical progress, but not breakthrough technologies, as for example fuel cells supplied with network hydrogen or widespread solar passive housing.
Energy efficiency is therefore captured in VLEEM in two ways. First, because there is an uncertainty about the nature of the technical progress and its relation to energy efficiency. Second, because the relation of useful energy to energy demand involves more or less eficient energy forms and efficient conversion devices. These two sources of uncertainty show the scope of energy efficiency improvement in the very long term energy demand, even in the same technology paradigm.

According to the ultimate purpose of VLEEM – modelling sustainable pictures of the energy system over a century - the initial assessment of the useful energy has then to be modified when accounting for a **new technology paradigm**. For example, in a paradigm built up around renewable energies, a widespread development of solar passive housing would logically take place, and the useful energy related to the thermal comfort energy services would decrease substancially as compared to the existing paradigm.

1.3 From useful energy to final energy demand

In very general terms, any energy product can supply any requirement for useful energy: only the efficiency with which this is done (and therefore the quantities), and the cost (because of the quality requested) will differ greatly among energy products according to the quality of the useful energy to be fulfilled.
Efficiency depends on the **exergy** potential of the energy product (i.e. the amount of work likely to be produced by 1 GJ of the energy product) as compared to the exergy level required by the energy service (very low in case of space heating or very high for computers for example): the less efficient the energy product for a given energy service, the higher the quantities of primary energy requested for this service.
Cost depends on physical parameters of the supply, such as production unit size, transport/distribution networks requirement, storage requirements etc.. The more centralised the production, the bigger the economies of scale for production, but the higher the transport/distribution costs. The more decentralised the production, the bigger the economies of series, and the lower the transport/distribution costs.

Three criteria are used to specify the quality of the useful energy requirement corresponding to the needs of energy services:

- The spatial dispersion of the needs, with two main areas: urban/sub-urban, rural.
- The power requirement at the spot where the individual needs are expressed, with three main levels: low, medium, high.
- The exergy level of the energy service, with four main levels: low, medium, high stationary, high mobile

The useful energy requirement corresponding to the needs of energy services in a given technology paradigm, and a given energy efficiency context, will be ultimately displayed in matrices based on these criteria.

Within each box of the matrix, the market shares of the energy forms depend first on the technology paradigm (availability and costs of the energy forms) and second on the quality requested for the useful energy within the box. The final energy demand, in a given energy efficiency context, result from these market shares and from the relative efficiencies of the energy forms in that box.

2 Modelling the dynamics of the needs of energy services and related useful energy: drivers and invariants

The determinants of the needs of energy services considered in VLEEM are mostly physical : population, hours of time-budgets, dwellings, crops, etc. Their expression is usually not time dependant, but the quantities involved are.

Although back-casting is the core philosophy of VLEEM, it is rather obvious that many of these determinants are not to be grasped in a normative way. For example, the question "which world population in 2100 would contribute to solve the green-house-gas problem" is out of the scope of VLEEM. Therefore, in the energy demand modelling principles, back casting is restricted to the expression of the energy services in relation to the technology paradigm (for example, how to supply fast mobility to contribute to stabilizing the CO2 concentration of the atmosphere), and modeling determinants of these needs are addressed in a more classical extrapolatory way (forecasting philosophy).

In order to produce robust and understandable results, any extrapolatory approach and model has to be constructed upon "invariants" which are clearly identified and demonstrated. In VLEEM, invariants have to refer to phenomena that do not change - or change very slowly – over one century, and to changes which occur at a fairly stable rhythm over the very long term (so called "heavy tendencies"). Such invariants obviously pre-suppose that certain global conditions are fulfilled, as for example no nuclear war or no major natural catastrophe will occur.

We will review below the main drivers and invariants considered in VLEEM, for the three main economic categories: the individuals, the economic production system, the transport system.

Energy services of individuals

Two main families of drivers are considered for the dynamics of the energy services of the individuals:

- The demographic drivers, which drive the volume of population and the number of households per socio-cultural cohort, by main world region: **fertility**, **mortality**, **nuptiality**, **migrations** inside and outside the world regions
- The development drivers, which drive the intensity of the needs of each person/household within the cohorts, in relation to the structure of the time budget among socio cultural functions, and which drive the changes in this structure of the time budget: personal **affluence** and **information** incorporated in the economic system.

In VLEEM, the “information incorporated in the economic system” plays a key role. Its level is "quantified" with an indicator calculated from a weighted average education level of the population: indeed, information incorporated in technologies and organisation is useful (in economic and social terms) only to the extent to which it can been mastered by people and workers. Therefore, there is a dynamic relation between the time spent in the education system by the children, the youngsters and the workers, and the information level of the economic system. This time spent in the education system is part of the time budget for "self accomplishment" and conflicts to some extent with the time budget for working for money. In that sense, increasing the information level of an economic system may be at the expense of a reduced increase of the volume of production.
Affluence is the combined result of the volume of production, i.e. the population at work multiplied by the time budget for working for money, the information incorporated in the economic system and the population.

Invariance is primarily embodied in the model through the repartition of the world population among socio-cultural-generational cohorts in which the life-styles and behaviours are fairly homogeneous and stable over time (life-styles and behaviours are considered to be fundamentally acquired by people before 25 years old, and to change only marginally afterwards).
The changes in the world population and its repartition among the cohorts are also bound to some key invariants:

- male/female distribution in birth
- minimum age for the head of household

- fertility age span for women.
- maximum rural population.

Other invariants concern the mechanisms through which time-budgets change from one generation to the next, with affluence and information, and how this affects the needs for energy services.

Energy services of the economic production system

Three majors drivers are considered for the dynamics of the needs of energy services of the economic production sytem:

- The number of paid work hours, i.e. the number of people available for paid work, according to age slice, multiplied by the time budget for working for money, for each cohort.
- The information level of the economic system (see above for definition)
- The bulk materials mobilised in the various socio economics functions.

The **volume of production** is appraised as the product of the number of paid work hours by the information level.
Information is considered in VLEEM as the only driver in the global dynamic relation between the volume of economic production and the overall requirement of useful energy by the production system (CHEN, 1996) .
The structure (among quality criteria) of the useful energy requirements related to the needs of energy services is driven by two major influences:

- The information level
- The bulk materials mobilised in the various socio economics functions .

The production system modelling is based on two main invariants embodied in two sets of universal (across regions and time) relations:

- Relations to link the amount of useful energy requested per unit of production volume with the information level: overall needs, high stationary exergy needs, feedstocks.
- Relations to link the amount of bulk materials per inhabitant, associated with the various socio-cultural functions, with the information level.

Energy services of the transport system

Two drivers are considered for the dynamics of the **freight transport**:

- The volume of production
- The population.

The freight traffic per inhabitant (in ton-km) is assumed to be driven only by the overall volume of production, which is considered to capture both the amount of goods to be moved and the size of the economic zone on which exchanges take place. The change in the volume of production coincides also with modifications in the organisation of the production: this brings about modifications in the structure of the flows of goods according to requested delivery delays and rhythms. All this drives changes in the freight transport modes and organisation, with consequences on the average speed.

Three major influences are driving the needs of energy services of the passenger transport:

- the affluence
- the population
- the structure of the households.

The annual mobility of individuals (in km/year/pers) is assumed to be driven only by the average speed of movement, the time-budget for transport being constant (ZAHAVI, 1973) (GRUBLER, 1991). The average speed is assumed to be driven by the affluence only. The allocation of the mobility between private and public modes results from the equipment ratio of individuals in private means of transport and the average speed of the individual means, which is driven by the affluence. Equipment ratios are determined by the affluence, but with saturation levels which are specific for each category of households.

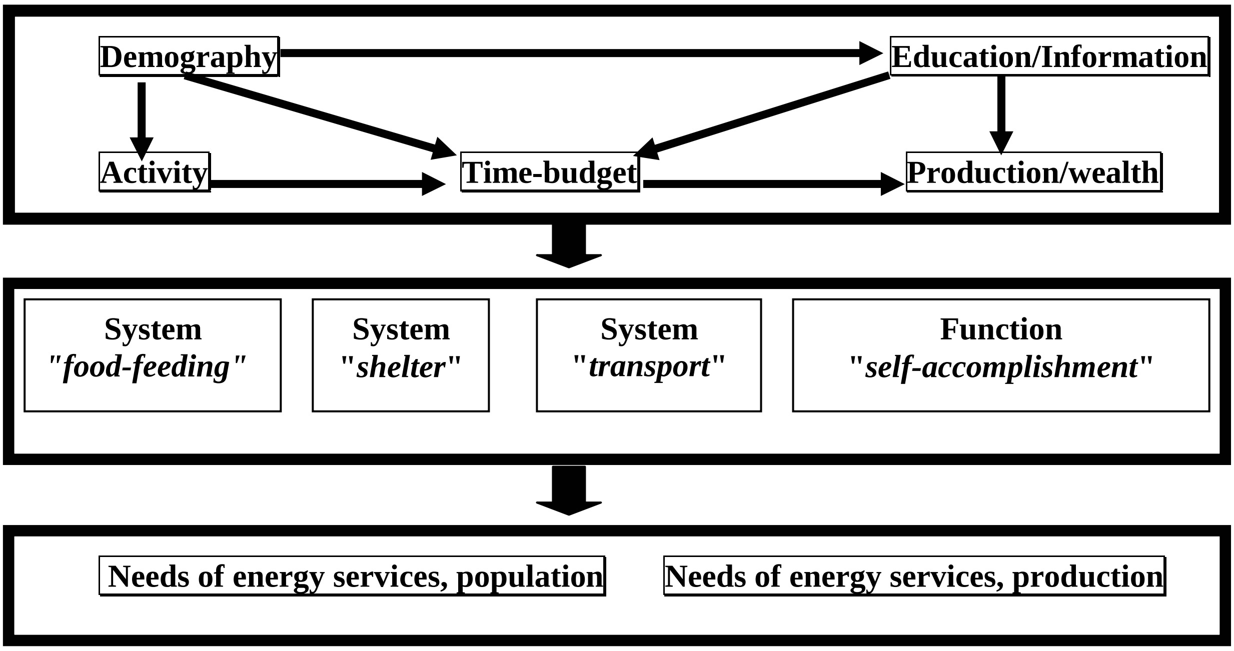
Invariants considered in the transport modelling are the following:

- The average time used in transportation per person is kept constant, the existing infrastructures are supposed to remain for at least one century, and there is a single function (not time dependant) to link transportation speed with affluence, for all transportation modes and for cars.
- For freight, the existing infrastructures are also supposed to remain for at least one century, and there is a single function (not time dependant) to link the freight traffic per inhabitant with the total production volume in the one side, and a single function (not time dependant) to link the average freight traffic speed with the production volume in the other side.
- There is a single function (not time dependant) to link the needs for energy services with the speed, according to transport infrastructures and modes for passengers, for all transport for freight.

3. Structure and general specifications of BASES (BASics of Energy Services), the demand sub-model of VLEEM

3.1 General structure of BASES

The general structure of BASES is summarized in the functional diagram simplified below.



The model runs on a 25 years step, from 2000 to 2100.

It is segmented in 10 major regions of the world:
- Europe
- North America
- Latin America
- The Asia-Pacific OECD
- CEI
- China
- South Asia
- Other Asia
- North-East Africa and Middle East
- Sub-Saharan Africa

The ultimate results of the model consist in matrices of energy services expressed in useful energy , as shown below with examples refering to conventional end-uses.

Exergy Density	**Low**	**Medium**	**High, stationary**	**High, mobile**
Spread, low	Hot water, rural	cooking, rural	lighting, rural	mobility, rural
medium	Swimming pool, rural	Drying crops	Machinery, rural	Farm engines
high	Green houses	Isolated indust. steam	Food processing	
Concent, low	Space heating, urban	cooking, urban	TV, urban	mobility, urban
medium	Space heating urban offices	Steam, textile indust. zone	Industrial machinery	Road freight transport
high	Industrial washing	Steam, chemic indust. zone	Cement factory	Planes

3.2 Modelling the socio-economic context of the socio-cultural functions: from demography to information, time-budgets and wealth

Demography

Demography is the most important driver in VLEEM. The function of the " Demography " sub-model is to project, every 25 years:
- the population by age groups and living zones
- the number of households by type, age of the head of household, and social grouping
- the average number of people per household and the average number of children by household of more than two people.

It is structured in the following way:
- 4 age groups for the population: <25 years; 25-49; 50-74; >74
- 3 zones of habitation/ social groupings: rural, urban, sub-urban/migrants
- 4 sets of households: households of one person, monoparental with a child, other households of two people, households of more than two people

Its inputs are:
- the rates of fertility of women per age group, with and without marriage
- the infant mortality and probabilities of survival according to the age
- the maximum rural population and external migratory flows.

Information/education

This sub-model aims at projecting the level of information of the socio-economic system, which is one of the key driving force in VLEEM.
It is structured in the following way:
- three formation cycles: primary education, secondary, tertiary -superior
- 4 age groups (cf above)
- 3 social groupings: urban, rural, migrants.

Its inputs are:
- the rates of effective schooling per cycle
- the relative contents in " information " of the cycles
- the population by age group

This sub-model relies on the following fundamental assumption**:** the level of information of a person during its life is determined by the highest cycle of initial formation reached.

People activity

This sub-model “activity” aims at projecting the maximum level of economic activity of the population, per average person, age group and social zone. This information provides the ultimate boundary of the labour force, which, in VLEEM, is one of the two fundamental production factor with the information.
It is structured in the following way:
- 3 age groups for the head of household (all except 0-24 years)
- 4 sets of households (all sets, cf above)
- 2 zones of habitation/ social groupings: rural, urban+sub-urban/migrants
- 3 statutes for the active people: head of household, partner, child

Its inputs are:
- the retirement age
- maximum rates of activity according to the statute of the active people
- the number of children for the households of more than two people

Time-budgets

Time-budgets, expression of life styles, are also important drivers in VLEEM. The function of the sub-model “time-budget” is to project the change in the structure of the time-budget among the main socio-cultural functions, and more precisely:
- the average number of hours devoted to the function " food and feeding "
- the average number of hours devoted to the function " paid work "
- the average number of hours devoted to the function " self-accomplishment ".

It is assumed that the share of the time-budget devoted to the function " shelter and lodging " is the same for all, equal one to 35% , and that the time-budget devoted on average to transport is the same for all, equal to one hour per day (ZAHAVI,1973).
The sub-model is structured in the following way:
- 4 explicit socio-cultural functions: food and feeding, shelter and lodging, self-accomplishment, paid work; an implicit function: mobility
- 3 age groups for the head of household
- 2 zones of habitation/ social groupings: rural, urban+sub-urban/migrants

Its inputs are:
- the share of the time-budget of the household devoted to the function food and feeding
- the recorded/legal rhythms of paid work

- the average activity rate per average person of a household
- the number of children for the households of more than two people

Production of wealth

The sub-model “production of wealth” stands for the macro-economic sub-model of VLEEM. It is structured according to the three social/habitat zones: urban, rural, migrants.
Its inputs are:
- the level of information of the socio-economic system
- the volume of labour force, in paid work hours
- the actual utilisation ratio of the potential of production

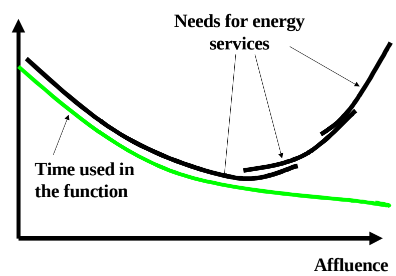
Its outputs are:
- the potential and actual volumes of production (in index)
- the purchasing power parity on the international market (in index)
- the wealth created (in index)
- the average affluence of the population (in index)

3.3 Modelling the needs of energy services in the socio-cultural functions

In very general terms, for each socio-cultural function, the needs of energy services are related to production or affluence through constant elasticities which are calibrated over the past; useful energy per unit of energy service is related to information level through constant elasticities which are either calibrated on the past (trend) or associated to specific development of end-use technologies (energy efficiency scenarios).

Food and feeding

As affluence increases, time budget for "food and feeding" decreases, and needs of energy services diversify and expand.



To account for this phenomena, the sub-model " food and feeding " is structured in the following way:
- needs of individuals versus food production
- 9 " energy services “ for individuals, 7 for food production
- 5 sets of basic food products: cereals and oilseeds, fresh products, meats, products from water and sea, drinks
- 2 modes of production: self-subsistence, production for others

Its inputs are:
- for food production: cultivated, irrigated and not irrigated surfaces; yields; rates of fertilizers and pesticides; in take of products from water and sea; populations; the

share of the self-subsistence in the cultivated areas and fishing; useful energy corresponding to each energy service for the base year; elasticities
- for needs of individuals: level of information; affluence; average time-budget per average person; population per cohort; useful energy corresponding to each energy service for the base year; elasticities

Its outputs are:
- quantities of basic food products produced by the agricultural system
- quantities of fertilisers and pesticides consumed
- needs of energy services, expressed by the useful energy, for each energy service in 2100, for each cohort;
- the matrix of the needs of energy services (expressed by the useful energy)

Shelter and lodging

The bulk of energy services for "shelter and lodging" is for getting in-door comfort: heating/cooling/drying the in-door space, lighting, …Therefore, the relation between the needs for energy services and the time budget in this function is rather loose. Climate conditions, affluence and information incorporated in the economic system are the major drivers of these needs, with differences obviously according to cultural habits.

To account for these relations, the sub-model " shelter and lodging " is structured in the following way:
- needs of individuals versus production/maintance/equipment of dwellings
- 6 " energy services " for individuals, 4 for production/maintenance/equipment
- 2 modes of production/maintenance of dwellings: self-construction/maintenance, production for others

Its inputs are:
- for production/maintance/equipment of dwellings: quantities of materials entering the construction and the maintenance of the habitat and of its comfort equipment, as well as the vehicles mobilized in the production and the maintenance of the habitat; useful energy corresponding to each energy service for the base year; elasticities
- for needs of individuals: level of information; affluence; population per cohort; useful energy corresponding to each energy service for the base year; elasticities

Its outputs are:
- needs of energy services, expressed by the useful energy, for each energy service in 2100, for each cohort;
- the matrix of the needs of energy services (expressed by the useful energy)

Self accomplishment

Within the time budget for self accomplishment, that for travelling and visiting is the most important as regard energy. In general terms, time budget for self accomplishment is in direct competition with the time budget for working for money. Affluence is mostly proportional to the time budget for paid work and to the information content of the labour. As a result, time budget for self accomplishment tends to decrease with affluence for a given information level; but for the same level of affluence, an increase in information level tends to increase the time available for self-accomplishment. As time budget for self accomplishment increases, time budget for travelling and visiting increases, at least at a similar speed.

The sub-model accounts 4 energy services for individuals and does not consider separately the production of goods and services for self-accomplishment: this production is included either in thr transport sub-model or in the “remaining production” sub-model.
Its inputs are: level of information; affluence; average time budget per average person, per cohort; population per cohort; useful energy corresponding to each energy service for the base year; elasticities
Its outputs are:

- needs of energy services, expressed by the useful energy, for each energy service in 2100, for each cohort;
- the matrix of the needs of energy services (expressed by the useful energy)

Working for money and remaining production

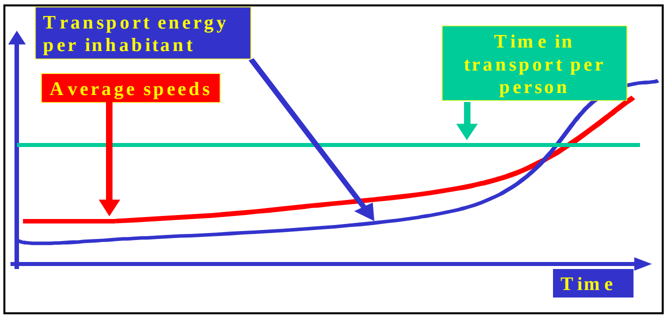
"Working for money" induce all the needs for energy services of the production system. Part of them are directly attached to the former socio-cultural functions (food and feeding, shelter and lodging); part are attached to the transport system (see below). We considere here the needs of energy services of the reamaining part of the production.
As explained earlier, the amount of (useful) energy requested per unit of production (the so-called energy intensity of the GDP in usual energy analysis), is considered a direct function of the information incorporated in the technology and organisation of the production system (including the skill of the workers), as shown by (CHEN, 1996).
In a given technology paradigm, it is considered also possible to capture with some relevance the amount of bulk materials involved in the primary transformations as a function of population and affluence.
These relations are eventually used to elaborate the matrix of energy services of the remaining production (outside what is already accounted directly in the former socio-cultural functions and in transport).

There is no specific need of energy services by individuals for the function “working for money” “The sub-model " needs of energy services for the remaining production " accounts for 4 energy services.
Its inputs are: the level of information of the socio-economic system, the total volume of production, the useful energy required by the whole production system for each energy service at the base year, the elasticities of the (useful) energy intensities to the index of information of the socio-economic system, for the whole production system.
Its outputs are:

- the needs of energy services, expressed by the useful energy, for each energy service in 2100, for the whole production system, and for the remainder of the production (outside food, habitat and transport productions)
- the matrix of the needs of energy services (expressed by the useful energy)

Transportation

Transportation is mostly an induced activity either by the socio-cultural functions or by the production, which can be assessed within theses categories or as a separate system. In VLEEM, transportation is assessed separately . Only in a few cases, mobility can be considered as integrated in the function "self accomplishment" itself (tourism), which can raise a difficulty when assessing transportation as a separate system. Needs for energy services for transportation are not just a matter of movement of people and freight on certain distances, it is also –and mainly- a matter of speed.



The spatial organisation of production and exchange of goods is the basic driver of the distance on which goods are moved. But, depending on the stage of the production process and its degree of sophistication (i.e. information content in technologies and organisation) the speed requested for the delivery of goods changes.

The sub-model " needs of energy services for transport " is structured in the following way:

- passenger transport versus freight transport versus production/maintenance of infrastructures and equipment
- 3 energy services for passenger: " soft " modes, individual vehicles, collective transport, 1 energy service for freight, 3 energy services for the production/maintenance of infrastructures and equipment
- 3 infrastructures: road, rail, air

Its inputs are:

- passengers: traffics and average speeds by mode at the base year, population and the number of households per type, affluence, the level of information;
- freight : traffics and average speeds by mode at the base year, the volume of production, the level of information
- production/maintenance of infrastructures and equipment: traffics, the level of information

Its outputs are:

- passengers: the rate of equipment of the households in motorized individual modes of transport, the hours spent in transport the average speeds, overall and by mode, the useful energy by mode, per passenger-km;
- freight: the total traffic of goods (ton-km), the average speed, the useful energy per ton-km, all modes
- all: the matrix of the needs of energy services in useful energy

4 A preliminary quantitative outlook for the EU-15

A preliminary quantitative application of this skeleton demand model has been carried out for one sub-region of the world, the EU-15.

EU population and households development is assumed to be driven by three major forces:

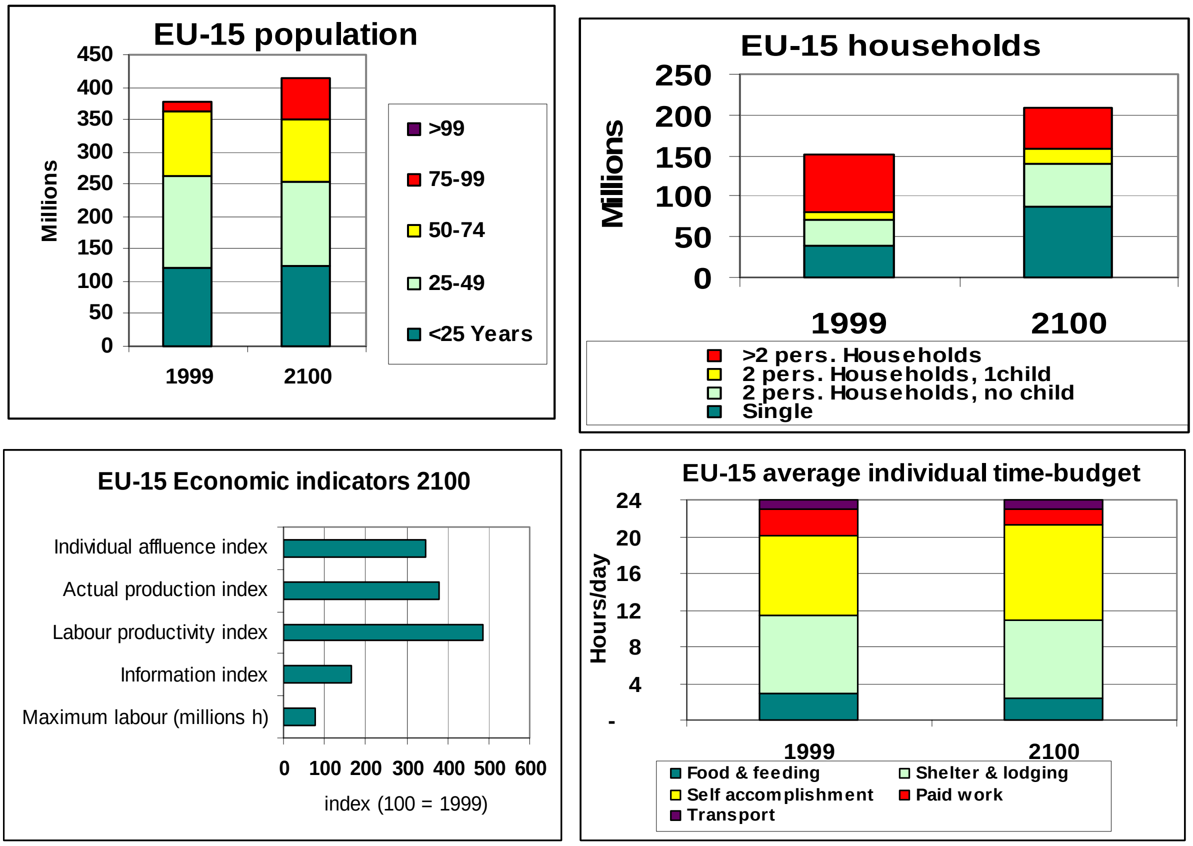
- re-increase in the fertility rate, from 1.4 children/woman today up to 1.8 in 2100;
- immigration from other world region, with an average flow of 2 millions persons/year (necessary for social and economic equilibria);
- trend towards more households with one person and monoparental.

The EU economy development is mostly driven by the labour force (a direct consequence of the demography) and the information level : this latter is progressing by 64%, mostly as a consequence of an enrolment level in the tertiary education system which is assumed to reach 70% of an age class (against 50% today). It is nevertheless assumed to be constrained by three social aspirations: lowering in the retirement age (60 years against 65 today in average), more holidays and vacations (7 weeks free against 5 today in average), reduced weekly working time (30 hours/week against 39 today).

Apart the assumptions on households structures and working rhythms, the life-styles are assumed to be driven by three main forces: an increased participation of women in the professional life, a reduction in the percentage of the time-budget allocated to the "food and feeding " function (minus 2 points), the generalisation of the private modes of transport.

These basic assumptions give the following socio-economic picture of the EU-15 in 2100.

Figure 1: EU-15 from 1999 to 2100: main socio-economic evolutions



According to the end-use technology paradigm of today, and with “business-as-usual” energy efficiency, the needs of energy services resulting from this socio-economic picture would change as depicted on table 1 and figure 2 below (useful energy).

Table 1 : Energy services in EU-15, 1999 and 2100

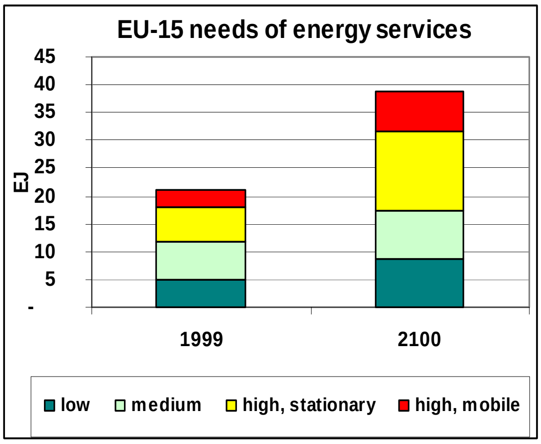
1999, EJ

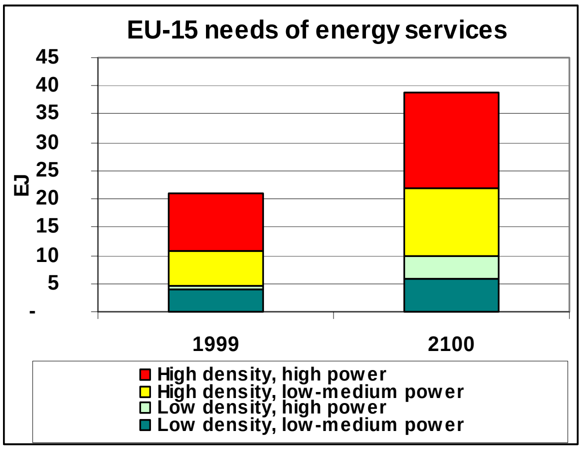
Density	Power	Exergy low	Exergy medium	Exergy high, stationary	Exergy high, mobile	Total
Low	low	1,1	0,1	0,3	0,8	2,3
	medium	0,0	0,0	0,0	1,5	1,5
	high	0,0	0,5	0,4	0,0	0,9
High	low	3,8	0,4	0,7	0,8	5,7
	medium	0,0	0,0	0,2	0,0	0,2
	high	0,0	5,9	4,4	0,1	10,4
Total		4,9	7,0	6,0	3,2	21,0

2100, EJ

Density	Power	Exergy low	Exergy medium	Exergy high, stationary	Exergy high, mobile	Total
Low	low	1,0	0,0	0,3	1,7	3,1
	medium	0,0	0,0	0,0	2,6	2,7
	high	0,0	2,1	2,1	0,0	4,2
High	low	7,8	0,4	1,6	1,7	11,5
	medium	0,0	0,0	0,3	0,0	0,3
	high	0,0	6,0	10,0	0,9	16,9
Total		8,8	8,6	14,3	7,0	38,7

Figure 2: Energy services in EU-15, 1999 and 2100





Three major findings can be drawn from these results:

- without any significant change in the existing technology paradigm on the demand side, and without significant change in the rationale for energy efficiency, the useful energy requirement of the EU-15 is about to double within the next century, which means a useful energy intensity of the GDP likely to decrease by 0.7% /year on the very long term;
- the growth is much more pronounced for the high exergy needs, both stationary and mobile, for which the efficiencies of the conversion from primary energy to useful energy are rather low when it is done through the Carnot cycle: this would result in the fact that the increase of the primary energy would be much higher than doubling, if the technology paradigm in the demand side remains mainly based on fossil fuels;
- 75% of the increase of useful energy requirement correspond to energy services located in high density areas, which would certainly favour centralized/network energy solutions.