Evaluating the potential for energy consumption reduction through urban renewal: quantitative modelling from the French Census

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SUMMARY – Nous présentons un modèle de calcul des consommations énergétiques attendues à la suite d'une opération de renouvellement urbain. Ce modèle, qui utilise les données désagrégées du recensement de la population, estime les consommations attribuables au logement, à la mobilité domicile-travail, ainsi qu'aux autres mobilités. Il est désagrégé spatialement à la commune, et en partie à l'IRIS, qui est une division infra-communale, et prend en compte les caractéristiques socioéconomiques des futurs résidents attendus du projet. Il permet de comparer les futures consommations énergétiques du projet à celles de la commune, et d'évaluer les bénéfices éventuels d'un investissement plus important dans les transports en commun ou dans l'efficacité énergétique des bâtiments. L'application de notre modèle sur deux municipalités *a priori* similaires montre son intérêt pour aider à définir des projets efficaces sur le plan des consommations énergétiques.

Keywords: energy efficiency, modelling, urban renewal operations

1. INTRODUCTION – We present in this paper a method to evaluate the potential for energy consumption reduction in urban renewal projects. Our method integrates three major issues for energy consumption reduction: building, mobility and lifestyle. We believe that this integrated method could secure better decisions in urban renewal projects. It has been implemented in the IMPETUS model in the framework of a research project involving researchers, engineers, property developers and cities.

Energy efficiency is a key objective for Europe because of the increasing cost of energy, the European dependence on fossil energy and the associated geopolitical risk. In 2008 the European Council adopted the climate and energy package that defines the 20-20-20 targets: by 2020, the 27 member states must implement policies to reduce by 20% the emissions of greenhouse gases (GES), increase by 20% the energy efficiency in Europe and reach 20% of renewable energy in energy consumption in Europe. Energy poverty (powerty) is also rising all over Europe . As in other European countries, French policies have failed in their attempts at decreasing energy consumption for various reasons. The energy bill for France went above overall French balance of payment deficit in 2012 at 70 Bn€ and more than 8 million French citizens fight against powerty (Devalière et al. 2011)

Overlooking the specificities of the territories on which national regulations are implemented is probably the most prominent reason for this failure. Car dependency and the energy consumption related to car usage vary according to the spatial distribution of housings and jobs, as well as the spatial distribution of amenities such as schools, hospitals, sport facilities, shops, etc. Energy consumption varies also greatly with respect to the socioeconomic features of the population and its behaviour at home. Our method tries to capture spatial factors as well as socioeconomic factors when assessing energy consumption for urban renewal operations. This is critical for the energy bill and the climate and even more so since the financial crisis and the increasing number of climate disasters.

Urban renewal operations try to combine good energy efficiency, nice living environment and low ecological footprint (Marique and Reiter, 2011; Souami, 2009; Beillan *et al.* 2011). They are associated in France to the *écoquartiers* approach (ecodistricts), often including local energy production and/or renewable energy solutions. Urban renewal operations are a means to foster energy efficiency in a city with energy-efficient buildings and the development and promotion of public transit networks. Housing and mobility are responsible for a large part of the total energy consumption per household (Berri, 2007; Raux and Traisnel 2007, Holden and Norland, 2005).
The aim of this paper is to offer a new methodology that precisely evaluates the potential for energy reduction in urban renewal operations. These operations encompass both building and transportation issues but also integrate energy consumption behaviour of expected inhabitants. This methodology, we believe, may be a breakthrough in the approach of consumption reduction problems for decision-makers and might lead, on the long run, to a shift in the urban socio-technical regime (Geels, 2011).

We used disaggregated data from the French Census to perform a territorial diagnosis of territorial energy consumptions attributed to housing and to transportation. By a specific filtering of these disaggregated data we were able to infer the profiles of the future inhabitants of an ecodistrict and their probable energy consumption. Depending on the specificities of each territory, we evaluated energy savings capabilities on housing and on transit. Then, we translated these data into costs. Owing to our methodology, the main stakeholders (city councils, the building industry and property owners) can eventually decide what fits most with their specific request or decide to redefine and improve their project.

The second section presents our methodology to evaluate energy consumption. The third section presents our two test cases. We will first describe the data and models we use for French municipalities. We will then illustrate our method based on two test cases of recent renewal projects located in the Paris region. These test cases illustrate the potential of our multi-step approach method allowing fine-tuning for energy efficiency on urban renewal project. We will eventually conclude in the last section by giving an illustration of the expected use of this methodology.

2. METHODOLOGY – Overall city energy consumption for housing, mobility, food and leisure among others increases with the number of inhabitants. French and European policies concentrate on housing and mobility. Each urban renewal is a unique opportunity to lower the average energy consumption per inhabitant based on these two sectors. Urban renewal also addresses lifestyle of inhabitants and its consequence on energy

consumption related to mobility and housing. Understanding and assessing lifestyle habits has until now been a far more complicated issue to tackle (Fink *et al.*, 2011).

Our objective is to enable the precise evaluation of the total energy consumption and expected savings at three levels. The first level is the thermic quality of the building. The second level is the location and proximity of a project to public transportation. The third level, which brings a new breakthrough both for research and operating work, is the future profile of inhabitants, their associated lifestyle and their associated energy consumption. These three aspects usually greatly differ from those of long-time inhabitants, especially those living in individual houses.

The French census from INSEE (Institut National de la Statistique et des Etudes Economiques) provides individual data that give detailed information on aspects such as household composition, age, level of education and occupation. It indicates where individuals work and their preferred means to commute. The census provides also information on housing, among which the number of rooms, type and comfort level of housing and the age of the building. These pieces of information are spread out across three different files: one pertaining to the commuting to work, one for housing and one for residential mobility. But since no unique identifier does link each individual in these different files, we had to define keys to link these files and extract the information required.

Our approach to assess energy consumption of the new urban project is the following. Based on socio-economic rules, future inhabitants of a new building share the same socioeconomic profile as those who settled in the past five years in similar and recent buildings (less that ten years old). With a computing filter we select among all individuals in the census those who have the same profile as those who will likely move to the new project. As for the population, we assume that the new project will leave the image and attraction of the city unchanged, and that people who will settle in the future building are the same as those who have settled in a recent past. This is quite a conservative approach to consider that an eco-district will have no impact on the inhabitants' behaviour. However, recent studies (Schwanen *et al.*, 2012, Sorrel, 2007; Bartiaux et Salmon, 2012; Garabuau-Moussaoui, 2007) show that energy gains tend to be absorbed by changes in behaviour, which is often called "rebound effect". This is why we also compute a scenario that encompasses an important though realistic change in transit use.

As said before, the watermark to assess energy efficiency is by determining if the new inhabitants will consume more or less energy than those already living in the city. New inhabitants might consume less energy for housing and benefit from the implementation of new techniques and new regulations for energy efficiency in the building sector. However, they might very well end up using their individual cars more often and commute farther than other inhabitants of the city, thus leading to higher total energy consumption. In such cases significant efforts must be made on public transport accessibility. Therefore, all our evaluations will be relative. We processed the average energy consumption figures of current inhabitants of the city and the average energy consumption of future inhabitants to evaluate the energy efficiency of the project.
We first processed two absolute scenarii for energy efficiency, ranking objectives in terms of importance, before we evaluated the project more accurately.

The first scenario corresponds to a zero-energy consumption building case. The second scenario represents the optimal location of a project regarding public transportation possibilities. By comparing these two scenarii with the current situation, we will then decide if the emphasis must be put primarily on the thermic performance of the building or on the accessibility of the public transportation network.

Owing to our method based on evaluating average situations and comparing them, one can choose to include whatever criterion they see fit in the processing, provided that the hypothesis are clear enough.

As for housing, we chose to focus on the energy necessary for providing heating and sanitary hot water. To make calculation easier, we made the assumption that the other energy consumptions caused by lighting and domestic appliances (what is called specific energy) will be the same for all city inhabitants, wherever they live. We know that this assumption is unrealistic, since specific energy consumption probably depends on the income of households, but this would require huge and somehow imprecise additional work compared to a low energy saving potential. For existing buildings, the French census gives us information about the kind of heating system: individual and electrically powered, individual with natural gas, collective. This mainly makes a difference as far as the energy bill is concerned, because natural gas is much cheaper per kWh than electricity in France. All new projects we studied have individual and electrical heating systems.

As far as mobility is concerned, we know that a large part of energy consumption is due to middle and long distance trips. Again, this consumption is correlated to the income of households but we can't precisely evaluate this effect without further field research based on a very precise population. We include all the mobility other that commuting to work even if the new project has little impact on it because it helps to evaluate the order of magnitude of energy consumptions due to heating and to daily mobility.

We eventually converted energy consumptions into energy bills to evaluate if the increased energy efficiency is economically viable. We used the average price of electricity in France at 0.12€ per kWh and at 0.05€ for natural gas. The average price for liquid gas is 1.5€ per litre. We will see that this price has little effect on the final energy bill. We also indicated the rental price (or of the virtual rent that an owner would pay to himself) to illustrate that, due to the French national energy model on one side, and on the French urban model on the other side, the energy bill for individuals is still very low compared to expensive rents in the Paris region.

2.1 - *Evaluation of energy consumption at the municipality scale* – The evaluation of energy consumption at the municipality scale is quite straightforward. With INSEE data, we know who commutes by car and who commutes by public transport. We then convert the distances into energy consumption via classical ratios. We assume that an individual car for short distances has an average consumption of 8 litres of gas per 100 km. As 1 litre of gas corresponds to 9.63 kWh and 1 litre of gasoil to 10.74 kWh we may safely assume that 1 litre of fuel corresponds to an energy consumption of 10 kWh. As for public transport, the computation is similar for distances. We use the fact that the average fuel consumption per user is around 4 litres per 100 km to convert distances into energy consumption. This means fuel consumption covers the case of almost empty buses in sparsely populated areas as well as energy efficient metros and railways.

Energy consumption due to housing is more difficult to assess accurately. In the cases we studied, energy performance certificates are given at the local scale, so that we know the average consumptions of individual houses and apartments according to their size and time of construction. The detailed files of the census contain all this information, with one line per housing, so that the computation of the actual energy consumption due to heating and sanitary hot water can be precisely evaluated. When energy certificates are not available we use regional energy factor, based on energy source (electricity, natural gas, renewable…) to estimate the energy bill.

Finally, we use the National Travel Survey to evaluate the order of magnitude of the energy consumption due to mobility other than work commuting. This estimate is performed only for ten categories of cities, according to their size and regional importance. It depends only on the size of the household.

2.2 - *Evaluation of energy consumption at the IRIS scale* – The French census contains a sub-city level called IRIS. IRIS is a subdivision for cities with 10,000 inhabitants or more. Each IRIS contains at least 2,000 inhabitants. The INSEE database provides information about housing at the IRIS scale. Our diagnosis is performed at this scale for housing consumption when energy certificates are available at this territorial level. However, we only have information about the mode used to commute to work for the reference person of each household (the man in a classical family). We therefore provide very useful information for our study but not the perfect one.

2.3 - *Evaluation of energy consumption of the future inhabitants* – The same assessment of energy consumption at the municipality scale is carried out as the former. In the detailed files, we select the lines representing households that moved in the last five years in a recent housing to match our criterion. Regarding energy consumption of housings, we do not have energy certificates but we know the standard that the new building will match. In France, all new residential building must match the "*A* label", that is to say less than 50 kWh/m^2/year. This figure of 50 kWh/m^2/year is modulated according to the latitude (the north region are colder) and to the altitude of the location. The first experiments have shown that this standard is for the moment difficult to match, so we consider that the actual energy consumption will be the bound of the *A* label, so 65 (50 multiplied by the regional coefficient of 1.3 for the Paris region) in this application.

2.4 - *Determination of bounds for energy savings* – Generally we will observe a large improvement in energy consumption for new projects, mainly because new buildings are much more energy-efficient than the older ones. However, we might want to investigate whether increased energy efficiency could be obtained by better housing efficiency or by greater accessibility to the public transit and hence higher transit modal share. The case of a better energy efficiency for housings is settled by choosing a better energy consumption, from 0 (passive building) to anything less than 50. The case of heavier transit use is processed by selecting the IRIS in the municipality that has the greatest public transit modal share. We assume that this modal share could be the one observed for the future inhabitants if transport supply were raised to an optimum level.

We also assume that it would be impossible to exceed this modal share given the spatial distribution of jobs and amenities. Thus we take into account the transit supply in the municipality and are able to give a plausible bound. It can be then decided to develop the accessibility to the transit network to reach this modal share at the location of the project.

3. TEST CASES, DATA AND MODELS – We present two urban renewal projects located in Villiers-le-Bel and in Sarcelles but very close to each other, in the north of the Paris region. Villiers-le-Bel is a small city of 25,000 inhabitants, with a fast regional train station. Sarcelles is a medium-sized city of 50,000 inhabitants also with a fast regional train station. Both projects contain a little more than 100 housings for total superficies of 8500 to 9000 m^2. Despite their similarities, these two projects yield different results that illustrate the interest of our diagnosis method. We first describe the data sources we use for the computation and then present the results of our model.

3.1 - *The French census* – The French census is represented through four detailed files containing the information of roughly one fourth of the total French population. The entire population can be described using the same samples included in the files. We use three out of the four files: MOBPRO file to give information on commuting trips from home to work, including commuting mode and location of the workplace, LOGMT file to describe housings, including number of rooms, age of the building and type of housing and MIGCOM file to describe mobility of citizens.

We use MOBPRO to process home-workplace distances, by associating cities with their geographical coordinates and using straight-line distances. The coordinates of cities are extracted from a geographical layer provided by Institut Géographique National, or IGN, which is the French State Agency for mapping. We use either centroids of municipalities or the coordinates of the administrative centres with very little differences in the results.

We use LOGMT together with energy certificate on the Paris region to compute the energy consumption (heating and sanitary hot water) of housings. Housings are located at the IRIS scale in the LOGMT file, so that we can have an estimate at the sub-city scale.

MIGCOM helps us selecting the people who settled down the city over the last five years. However, there is no key to find similar people (or the same people) in MIGCOM and in MOBPRO. The French census is a statistical database, including roughly one fourth of household and not all households have been included in the survey. We construct a key by merging the variables that are the same in both files. We can match more than 80% of the individuals in MIGCOM in MOBPRO and can determine the location of work and commuting mode for more than 80% of the subpopulation that we have selected as being similar to the one that will actually settle in the new project. Our matching key is composed of the age, socio-professional category, level of education, employment, position in the household, type of household, number of persons of the household, gender, housing type, housing status (owner or rent) and cohabitation mode. Then we identify in MOBPRO the people we focus on allowing us to represent their home to work transportation modes and distances.

3.2 - *Energy performance certificate from IAU-IDF* – The IAU-IDF is the urban agency in charge of the Paris region. The IAU-IDF has established energy certificates for housing at the IRIS scale by gathering and analysing energy bills, thermic surveys and models. These certificates for flats and individual houses vary mostly according to the age of the building and to the location. Fortunately for our study, IAU-IDF chose the same classes for ages for construction than the ones in the census, enabling a compliant computation of energetic footprints with LOGMT file.

4. TEST CASES – The fist project we introduce is Villiers-le-Bel. This project has 112 flats for 8,500m², making an average of 76m² per flat compared to an average of only 67m² for the entire city. This illustrates the major size issue on housing that is twofold. Increasing the size of flats per inhabitant (Traisnel, 2007) and the number of inhabitant per flat. In Villiers-le-Bel, both municipality and property developer choose to attract larger families.

Results are summed up in Table I. The overall project is by no doubt energy efficient for the city and for inhabitants.

Table I – Average energy consumption per household (in kWh) for Villiers-le-Bel's project

	Project	Municipality	Project at the best location for transit	Project with optimal housing efficiency
Housing	4,933	15,915	4,933	0
Commuting to work (car)	1,535	1,621	1,364	1,535
Commuting to work (transit)	579	525	617	579
Other mobility	6,046	6,046	6,046	6,046
Total	13,093	24,107	12,960	8,160

Source: authors' computation after the 2008 French Census from INSEE and energy certificates from IAU-IDF

Housings of the new project are more than five times more energy efficient than the average housing of the city. There are 9900 housing facilities in Villiers-le-Bel, including 77% flats. Many buildings were constructed in the 60s, 70s and the 80s are very poorly insulated. However, this huge saving on energy for housing is partly lost because new inhabitants in Villiers-le-Bel are expected to commute more frequently by car than the existing inhabitants (Table II). Average consumption for commuting is slightly lower than the one of the population of the city. We finally conclude on more than 40% total energy consumption savings expectation on Villiers-le-Bel project: 13,093 kWh to be compared to 2,107 kWh.

Table II – Car and transit modal share of the project (computed by our method), the city, and the best IRIS of the city as far as transit modal share is concerned in Villiers-le-Bel

	Project	Municipality	IRIS of the project	Best IRIS
Car modal share	49.0%	45.6%	33.7%	33.7%
Mean distance (car)	8.9 km	10.8km	-	-
Transit modal share	43.9%	45.9%	61.0%	61.0%
Mean distance (transit)	15.0 km	13.9km	-	-

Source: authors' computation after the 2008 French Census from INSEE

Table II reveals two features: 1) new inhabitants use the car to commute to work slightly more than the average of the city. 2) the project is located in the IRIS with the highest transit modal share. Thus we can expect higher transit modal share for the project than what our computation reveals. There is no room for improvement as far as transit is concerned, as new inhabitants are prone to using transit and the project location is optimal.

One can wonder what would be the benefits of a higher transit modal share and this is the object of the third column of Table I, where we make the assumption that new inhabitants have the same modal share as the one of their IRIS. We obtain that energy consumption due to commuting to work could be decreased, which however yield only a slight reduction of the total energy consumption. The option of a passive building would be much more efficient, with a total consumption of 8,160 kWh to compare to the 13,093 kWh of the project.

Additional local policy, incentive or specific communication can be later decided to change behaviour of inhabitants. While energy consumption is scarcely perceived as critical information for inhabitants, communicating on energy bills might change their behaviour. We have computed the energy bills associated to the energy consumptions of Table I (Table III).

Table III – Mean cost of energy per household (in € per year)

	Project	Municipality	Project at the best location for transit	Project with optimal housing efficiency
Housing	276	890	276	0
Commuting to work (car)	461	503	397	461
Commuting to work (transit)	-	-	-	-
Rent	17,486	12,840	17,486	18,738

Source: authors' computation after the 2008 French Census and energy certificates from IAU-IDF

We know that the commuting costs are hugely underestimated by commuters taking into account only the cost of energy of cars, which roughly represents 25% of the total cost. However, we see the order of magnitude of the financial gain that could be obtained with an increased use of transit, as well as the cost of new housings when compared to old ones (generally rents are 10 to 20% higher than the mean of similar housing), and the higher cost of passive building that is not compensated by energy savings in the short term.

We now turn to our second test case in Sarcelles. This test case gives a different diagnosis (Table IV). The new inhabitants use much more their car than those already in the municipality (Table V), and consume far more energy to commute: 1,879kWh instead of 1,347kWh. The ratio for housings is similar to the one we have observed for Villiers-le-Bel.

Table IV – Mean energy consumption per household (in kWh) in Sarcelles

	Project	Municipality	Project at the best location for transit	Project with optimal housing efficiency
Housing	3,108	16,352	3,108	0
Commuting to work (car)	1,879	1,347	1112	1,879
Commuting to work (transit)	384	585	662	384
Other mobility	6,531	6,531	6,531	6,531
Total	11,902	24,815	11,413	8,794

Source: authors' computation after the 2008 French Census from INSEE and energy certificates from IAU-IDF

Table V – Car and transit modal share of the project (computed by our method), the city, and the best IRIS of the city as far as transit modal share is concerned in Sarcelles

	Project	Municipality	IRIS of the project	Best IRIS
Car modal share	65.9%	37.1%	58.3%	28.2%
Mean distance (car)	8.1 km	10.7km	-	-
Transit modal share	31.2%	51.1%	33.5%	67,2%
Mean distance (transit)	14.0 km	13.5km	-	-

Source: authors' computation after the 2008 French Census from INSEE and energy certificates from IAU-IDF

However a close examination of Table V reveals that the very low public transit modal share is not only due to the fact that new inhabitants have probably higher income than the ones already living in the neighbourhood, but also that the project is located in an IRIS that has a poor accessibility to the transit network. Indeed, the rapid transit station is quite remote, so that the transit modal share of the IRIS is only 33.5%, lower than the mean of the city (51.1%) and very far from the modal share observed in the IRIS where the transit station is located (67.2%). This indicates that there is a clear path for improvement either by relocating the project closer to the transit station, or by adding a regular bus line to reach quickly the station. Table IV shows that a relocation of the project in such an optimal location could yield an energy reduction of almost 500 kWh (11,413 kWh instead of 11,902 kWh).

Table VI – Mean cost of energy per household (in € per year) in Sarcelles

	Project	Municipality	Project at the best location for transit	Project with optimal housing efficiency
Housing	174	915	174	0
Commuting to work (car)	564	412	326	564
Commuting to work (transit)	-	-	-	-
Rent	18,783	16,978	18,783	29,722

Source: authors' computation after the 2008 French Census from INSEE and energy certificates from IAU-IDF

When we look at the costs for the inhabitants (Table VI) we see that using more the transit would be quite interesting financially, and that the new housings enable an energy bill reduction of approximately 600€ per year, which is less than the difference in rent at the beginning when the flats are new but will quickly be interesting as soon as the rent will reach the mean level of the municipality. However, the option of a passive building seems to be less interesting, as the cost augmentation is much higher than what can be saved on the energy bills for the heating and the sanitary hot water.

These two test cases illustrate the fact that indeed energy efficiency is obtained with new houses. Domestic energy consumption can be cut by almost four by better insulation of buildings. However, the effect on the energy bill is not large enough to justify, on the sole economic basis, to go beyond the *A*-label standard given the fact that a better energy efficiency for buildings necessarily impacts housing prices. The test cases also illustrate that, even in dense suburban cities well connected to the transit network, working on transit accessibility can be very helpful, especially when there is a conjunction of medium accessibility and evolution of the population towards profiles less prone to use the public transit network.

4. CONCLUSION – Energy consumption reduction is a key objective for Europe, for which all member state must implement policies towards the 20-20-20 objectives. However, these policies must be tuned at a local level to be really efficient. National standards and regulation have proved to be insufficient. We have presented in this paper a new methodology that precisely evaluates the potential for energy reduction in urban renewal operations and help impulse better decisions. We evaluate and enable the precise evaluation of the total energy consumption and expected savings at three levels.

The first level is the thermic quality of the building. The second level is the location and proximity of a project with public transportation. The third level and the most innovative describes the future inhabitants profile, their associated lifestyle and their associated energy consumption that usually greatly differ from the inhabitants living in the city for a long time, especially those living in individual houses.

This model is now the corner stone of the IMPETUS method that consists in organising round tables with all the stakeholders of a urban renewal operation: property developers, city councils, land planners, transportation authorities, etc. The IMPETUS method has been developed in a research program associating EGIS (an engineering group involved in transport systems and land planning), ICADE (a property developer), the City of Paris, EIVP (the school of Paris civil engineers), CSTB (Scientific and Technical Center for Building) and LVMT. Besides the energetic aspects presented in this paper, the IMPETUS model also computes financial reports for the main stakeholders enabling to evaluate the feasibility and the profitability of the operation.

Our model has been tested on four real test cases in round tables involving several stakeholders of the projects. The returns on experiment for the first test cases are quite positive. The IMPETUS model has been found to be helpful by stakeholders and the hypotheses have been well accepted by all the participants.
Still, they have suggested two improvements:

- the use of the city as a reference for evaluation (which is imposed by the spatial resolution of the census) has been judged to be less pertinent than smaller urban divisions such as *quartiers* that gathers a few urban blocks;
- an increase in accessibility to transit has positive effects on the whole vicinity. This effect could probably be estimated and give a better insight on the choice between accessibility and building quality.

The IMPETUS method could also be turned in a near future in an optimisation model helping to define the characteristics and location of a project given an energy efficiency goal. This will be the object of future developments, as well as refinements on the way we select the socioeconomic profiles of future inhabitants given the nature of a project.

The IMPETUS method will probably be deployed by EGIS or ICADE in a near future. The profiling of the future inhabitants of the project improves standard computation The model solves also information asymmetry issue by giving each stakeholder the same level of information. This facilitates negotiation and helps the stockholders to decide on the project with the highest profitability for all of them and the highest energy efficiency.

ACKNOWLEDGEMENTS – This work has been funded by the ANR grant "IMPETUS". Part of this work has been presented during the IV EUGEO Congress, Roma, Italy, 5-7 September 2014, in the special session entitled "Interdependencies between policies, energy consumption, and global environmental change: a geographic perspective" organised by Dr. Federico Martellozzo.

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