Ecosystem Services Assessment Using InVEST as a Tool to Support Decision Making Process: Critical Issues and Opportunities

Andrea Arcidiacono, Silvia Ronchi(✉), and Stefano Salata

Department of Architecture and Urban Studies, Politecnico of Milano, Milan, Italy
{andrea.arcidiacono,silvia.ronchi,stefano.salata}@polimi.it

Abstract. The awareness of Ecosystem services concept has gained prominence in the decision making process. The inclusion of this issue strictly depends on the way in which may be incorporated in the development strategies of a region by the policy makers. The paper want to test one of the most used model to quantify the Ecosystem services, with a spatial distribution output, in order to recognize the critical issues and the opportunities to use it as a tool to support decision making process. The InVEST model was experimented for the Habitat Quality and Carbon Sequestration functions. The survey area is the Municipality of Lodi in the south part of Lombardy Region (north of Italy) due to the high accessibility to the database information and also to attempt the adaptability of the software to product reliable output at micro-scale.

Keywords: Ecosystem services · Invest model · Land use · Habitat quality · Carbon sequestration · Decision making

1 Introduction

In recent years defining, classifying, detecting, mapping, and evaluating Ecosystem Services (ES) has been the goal of several enlightening publications.

Ecosystem services studies and related application were investigated by major international initiatives, as the Millennium Ecosystem Assessment (MA)[1], The Economics of Ecosystems and Biodiversity (TEEB)[2] and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES)[3]. Despite increasing political attention on ES recently boosted because the socio-economic relevance on such issue is directly connected with the general objective of "sustainable development" which seems to be, at all, one of the pillar that steer contemporary decision making processes.

The awareness of the importance of ES generated different approaches to classification and evaluation of the Ecosystem functions with a doubled challenge

[1] www.millenniumassessment.org/
[2] www.teebweb.org/
[3] http://www.ipbes.net/

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regarding both conceptual and technical aspects. ES are commonly defined as the benefits that humans obtain from ecosystem functions [1], [2], or as direct and indirect contributions from Ecosystems to human well-being [3] [4]. With the rise of the ES concept and the increase of proposals for a more sustainable management of natural resources integrated with a sustainable development goal [2], it remains a double challenge that seems to capture the attention of research on such field: once ES has been defined by few pioneering studies, the literature is divided by who try to classify ES [5], and who try to evaluate ES [6]. In fact, the ES concept gained prominence in the ecological and economic literature for the attempt to classify and assess the services in compliance with several disciplines research methodologies, their methods of inquiry and their technical procedures.

At least, the aim of the ecological and economical disciplines focused on ES intend to standardize ES as a requirement to measure and to assess them in order to support the policy makers in the decision making process.

Recently, an important discussion concerning the definition of a common international classification of ES (CICES) has emerged [7]. ES classification is known as the list of benefits in terms of environmental goods or services; it helps the potential assessment of specific land use transformation during the time.

International agencies mainly focus on a common classification of ES as the standard baseline to share a common knowledge of disciplines around the issue. Nowadays the great deal of research for many studies is how to recognize, assess and map ES. In particular, the most important key of discussion for both ecological and economical disciplines, is the values of ES: what kind of value is correct to attribute?

Many existing tools and approaches for measuring, mapping and evaluating ES are still subject to deep scientific testing, nevertheless too often such analytical framework remains at the theoretical stage because it is composed by suppositions and proposals without an active perspective that could support the theory. This research paper try to put bridges between actual gap that separate theoretical stages and practical experiences on case of study.

Despite the most common application of ES mapping is done at macro-scale using national inventories of Land Use rather than European ones (Corine Land Cover), the tentative of the research is to apply it at micro-scale. According to the subsidiarity principle, which ask for a better detailed information to support the local policies, ES mapping in this paper provides an output highly precise.

By the way a tentative of integration of sustainable planning procedures will be presented using ES maps as proxy for the overall value of soils. Hereafter it will be showed how InVEST could be used as software for support the construction of an analytical framework for local town planning management.

2 Ecosystem Services, Land Use and Decision Making Process

The changes in land use affect ES values which increase or decrease on the base of the land use variation between different years. On the basis of knowledge on urban land use changes, the subsequent step is to evaluate their impact on natural ecosystems [8].

ES is the conditions, process, and components of the natural environment that provide both tangible and intangible benefits for sustaining and fulfilling human life [4]. Its measurement is codified: "The value of the world's ecosystem services and natural capital" [3] present an economic evaluation of the goods and services that human population derive, directly or indirectly, from Ecosystem functions.

The ES approach can explore the influence of land use and practices on natural capital stocks, on the processes that build and degrade these stocks, and on the flow of ES from the use of these stocks [9].

Connected to the land use changes and the observation of the land take by new urbanization, the evaluation of the ES help to enforce the decision making mechanism. In fact, land use change leading from urbanization often have a significant negative impact on the affected ecosystems and the goods and services that they provide [10]. Different land uses also influence the shaping of land cover and the amount of impervious surfaces; soil sealing is closely related to land take or land degradation. The management of soil sealing includes ecological, economic and social dimensions which need to be considered in line with sustainable urban management, This is why planning and policy have do identify a balance between these three dimensions [11]. In this sense, the integration of the ES approach into planning is crucial, and therefore should not be considered as an option, but an essential element; the lack of this element has to be tackled and compensated by planning discipline, even if it get involved the entire current planning approach.

Taking into consideration that soil performs many environmental, economic, social and cultural functions, the policy makers that act for steer land use planning process have to include contributions from different disciplines and theoretical background for more huge knowledge about ES and a better use of it .

Required integration should include, among others, the ecological systems that provide the services, the economic systems that benefit from them, and the institutions needed to develop effective codes for a sustainable use [12].

The design of environmental management policies frequently involves weighing up the consequences of proposed actions. It is necessary to consider impacts upon ecosystems as well as the social and economic systems to which they are linked.

Regarding to this issue, Costanza classified the global land use into sixteen primary categories and grouped ES into seventeen goods and services (gas regulation, climate regulation, disturbance regulation, water regulation, water supply, erosion control and sediment retention, soil formation, nutrient cycling, waste treatment, pollination, biological control, refugia, food production, raw materials, genetic resources, recreation and cultural), using this approach a lot of recent international bibliography has been dedicated to extract an equivalent weight factor per hectare in different areas [13]. The total ES for each land use category can be obtained through multiplying the area of each land category by the value coefficient:

$$ESV = \sum (Ai \bullet VCi) \quad (1)$$

Where ESV is the estimated ecosystem service value, Ai is the area (ha) and VCi is the value coefficient for land use category "i" (Helian et al. 2011). ESV is associated to a land use transition matrix, notable changes on ESV can be observed and the economic loss of specific transitions (in particular the diminishing of cropland or other natural covers in favor of new urbanized land) can be noted and explained.

New indicators (as the percent decrease of the total ESV) can enforce the evidence of economical long term effect of land use change and urbanization. Even simplified and theoretical, such method helps to improve the knowledge of qualitative effect of land use change, thus increasing the attention of cause-effect mechanism due by planning options.

Mostly ES analysis is useful to analyze the percent rate of increment or decrement of values rather than the total amount of ESV which can be substantially influenced by the methodology adopted (using Costanza's method the accuracy on estimating the coefficient values of the major land cover is crucial).

Up to now, few analyses are focused on environmental effect of land take to ES provided by natural soils [10], especially the ones which ask for integrative analysis across different disciplines [14]. It is quite recent, the research dedicated to estimate the environmental effects of land take process, especially using ES as a proxy [11] [15] [16].

From systematic studies on surface and covers, a huge amount of research on assessment of urban transformation in hydrologic system is focused on "what happened on topsoil and under it, when a process of urbanization occurs" [17].

In general, despite ES approach emerge as the main paradigm to estimate quantitative and qualitative land transformation [4] [3], there is a lack of technical assessment to introduce indicators that hold different multidimensional features of soil transformation (i.e. the alteration of productive capacity – land capability, waterproofing, biodiversity decrease, landscape and cultural values). Composite indicators on land take are far away from being rooted in scientific literature (even if they are well defined) [18], despite a broad rhetoric claiming for an interdisciplinary approach on land management, no systematic results seem to be achieved. The demand for profound soil knowledge is high [19] [20] and a major interaction of scientists from other disciplines is requested in order to achieve a broad holistic role in society, and the context of "fusion" between different background needs to be enforced [21] [8] [22] [23].

3 The InVEST Model

Starting from the assumption that the concept of ES can change the way ecosystems are considered in policy and planning by the promotion of regulative options that will reduce environmental degradation and biodiversity loss while enhancing human well-being. There are several obstacles that prevent the transition from theory to action.

One major obstacle is the lack of a more systemic and holistic agreement on a common considerations that land uses is co-determined by natural and socio-economic factors and their interaction. Such interaction request a high integration of knowledge between ecological, social, and economic theories and studies.

ES can contribute to enforce the above mentioned holistic approach, because its systematic assessment over the analytical framework for town planning can be pursued using 5 important steps: 1) framing of key policy issue related to ES preservation or restoration; 2) identify ES and users (e.g. the definition); 3) mapping and assessing status; 4) valuation; 5) assess policy options including distributional impacts.

As mentioned, between (1/2) framing/identifying and (4/5) evaluating/assessing policy, there is an in between phase (3), which is crucial for introduce a progressive shift from description to prescription and local regulation of ES: mapping and assessing the status of ES on a context based situation.

The importance of the mapping and assessment of ES with an integrated framework was reflected on the proliferation of different mechanisms, methods and procedures to ensure that the value of ES is visible in decision-making.

One of the possible way of mapping and assessing ES is the use of InVEST system (Integrated Valuation of Ecosystem Services and Tradeoffs) which is a free software developed during the Natural Capital Project, with the aim to align economic forces with conservation, by developing tools that make incorporation of natural capital into decisions, demonstrating also the power of these tools and by engaging leaders globally.

InVEST is a tool for geographic, economic and ecological accounting on ES, according with specific types of land uses/covers. It is especially designed for territorial and town planning evaluation. In particular the ones focused on environmental protection at local scale, and all the decisions aimed to restore or defend the natural capacity of soil to provide non market goods as biodiversity, carbon poll, etc.

The InVEST model may be useful for informing resource management strategies and quantitative ranking of scenarios that can aid decision making, also because is a powerful tool to explore possible results of scenario between different land use alternatives (it is especially useful to compare degrade or ecological upgrade of specific soil functions, even in economic terms) [24].

The ideation of InVEST depends strictly to the concept that ES must be explicitly and systematically integrated into decision making by individuals, corporations, and governments [25]. The aim of this tool is to inform managers and policy makers about the impacts of alternative resource management choices on the economy, human well-being, and the environment, in an integrated way.

InVEST has 17 models that valuate ES, both biophysical processes and processes with monetary/economic value. The results of this model is a map of the geographic area of focus, the model requires spatially explicit and works on a GIS platform, as well as data describing the biophysical properties of land use/land cover (LULC) types [26].

The software works with a standalone modality and provides specific output, asking for different data input. As well as the evaluation request a high account of precision, the software request a significant number and high quality of raw data. The software can also evaluate, for specific ES, the trend of upgrade or degrade for different LULC map (baseline, current, future).

Each model requires inputs relevant to the ES of interest and LULC data. Most model outputs are a series of maps that represent relative values for the aggregate data over the area of interest. The research presented in the paper use the last release available (in 2015) of the InVEST model (version 3.1.0). The InVEST functions selected for this preliminary research were Habitat Quality and Carbon Sequestration.

4 An InVEST Possible Application

The challenge in the application of the InVEST model is to make the ES framework credible, replicable, scalable and suitable.

The area chosen to experiment this software is the Municipality of Lodi, an Italian town of 44,000 inhabitants with a territorial extension of 41kmq located in the south part of the Lombardy region.

The modeling approach is time intensive and requires knowledge of local ecology as well as technical skill with geospatial software. The choice of Lodi as a tester area is due by the presence of different database useful to create the requested dataset for "running" the model. In fact, the creation of the input dataset is the most important aspect for the quality of the outputs. The data inputs required for each model vary depending on the service, with data formats in GIS raster grids, GIS shape files or database tables.

Moreover, it is important to specify that the application of InVEST strictly depends on the context and on the degree of detail of single data. In this sense, for example, in a low dense residential area the detection of the simple land use/cover change is highly affected by territorial morphology, by settlement typology, and by infrastructural distribution. By the way, territorial conditions weigh heavily the productions of maps of the model and the organization of input dataset (e.g the weights assigned to each single data) is crucial too.

In this case, it was used the Topographic Database (DBtop) elaborated for the Province of Lodi. The DBtop is the more detailed LULC framework used as a cartographic base for town planning instruments. The survey dates back to 2008 with a map scale up to 1:500 until 1:1.000. More than that, The Province of Lodi, and for instance the municipality of Lodi, is also a territorial context with high degree of additional geospatial information (Land Capability, constrains, protected areas, slopes, water protection layers and other GIS) freely downloadable from Geo web site of Italian Government[4].

A high degree of precision was required since the testing phase because, as mentioned, efficiency of the program is highly dependent from the reliability of maps. Raster output, for each services tested, was setted in high resolution (raster cell size 5*5 meters). The micro-scale range is a novelty aspect in the use of InVEST. This is extremely helpful if considering the planning phase central for sustainable policy making, and require a high degree of information on possible land use allocation.

4.1 Habitat Quality Index

This experimental application start with the "Habitat Quality model" that is the ability of the ecosystem to provide conditions appropriate for individual and population

[4] http://www.dati.gov.it/

persistence. Habitat with high quality is relatively intact and it's depends on a habitat proximity to human land uses and the intensity of these land uses.

Effects of land-use change range from habitat destruction and pollution to extensive modifications of global biogeochemical cycles. In a global perspective, land use change affect the matter cycles and the global climate and hydrology. As a result, this decline produce impacts in biodiversity and accordingly habitat loss, modification and simplification with reflection on the local system [28].

The model identify the habitat of a specific species or in a more generically way in order to estimate how common threats affect wide range of viable habitat in the selected area. In summary the InVEST indicator is related to the biodiversity module in order to assess terrestrial habitat quality combining information on land use-land cover (LULC) and threats to biodiversity (anthropogenic pressures).

Below are listed the input data required for InVEST model [27]:

- Current LULC map
- Threat data
- Accessibility to sources of degradation, that is the legal/institutional/social/physical barriers provide against threats.

Firstly was clipped the DBtop with the boundaries of the municipality of Lodi and after there was a class dissolve for each LULC element. LULC classes are:

- Class 1 (means urbanized areas: urban fabric plots, without streets and green private/public spaces);
- Class 1.2.2 (means street, parks, railways and technological spaces dedicated);
- Class 1.4 (means green urban areas, similar to class 1.4 of CLC, even with high degree of detail, for example, in this classes green private gardens on open urban fabric are recognized);
- Class 2 (means agricultural areas, as for CLC legend);
- Class 3 (means natural or seminatural areas, as for CLC legend);
- Class 4 and Class 5 (means water, as for classes 4 and 5 of CLC).

The input file were elaborated in a GIS platform using ArcGis 10.1 release. All single shape files were unified with union function, than a rasterization process for LULC map creation can be conducted. Rasterization was applied with a 5*5 meters cell size, with LULC code as pixel unit, using the maximum area of pixel as proxy to attribute the value.

After creating the LULC maps, it is necessary to define the "threat data". For the case study, the threats identified are the settlements (SET), streets (STR), urban green (UGR) and, finally, agriculture land (AGR).

Threats are articulated in:

- maximum distance over which each threat affects habitat quality (in kilometers);
- weight that is the impact of each threat on habitat quality relative to other threats, expressed with 1 at the highest to 0 at the lowest;
- decay distinguished in linear or potential depending on the function expressed;
- maps of threats.

Table 1. Scores assigned for each category

THREAT	MAX_DIST	WEIGHT	DECAY
SET	0,3	0,7	Linear
STR	0,5	1,0	Linear
UGR	0,1	0,2	Linear
AGR	0,2	0,4	Linear

The Accessibility of habitat to threat (social, political, geographical restrictions) was evaluated from 0 to 1 point in which 1 is fully accessible without any restrictions to the threats while 0 correspond to the area less likely to be access by threats. The input requires is a .csv file with the level of access and a shape file with the spatial distribution of the restriction.

Table 2. Accessibility to sources of degradation and Habitat type and sensitivity

LULC	NAME	HABITAT	L_set	L_str	L_ugr	L_agr
1	residential	0	0	0.4	0	0
122	street	0	0	0	0	0
14	urban green	0.5	0.5	0.4	0	0.1
2	agricultural	0.6	0.8	1	0	0
3	natural	1	1	1	0.2	0.5
45	water	1	1	1	0.3	0.5

The single inputs were included in the InVEST model. The outputs are two maps:

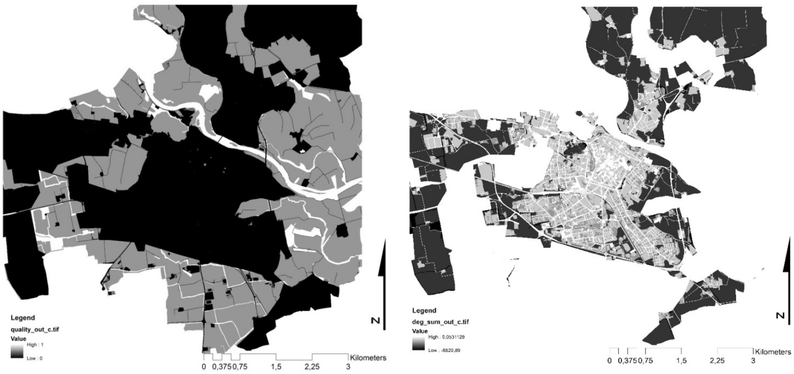

Fig. 1. Habitat quality map (left) and Habitat degradation (right)

This function can be used to evaluate how different scenarios of changes in land cover or habitat threats might affect the availability of quality habitat, and consequently biodiversity. A sort of parallel investigation related to the first one that illustrate the habitat degradation in a grey scale of color. The darken one are the landscape with high degradation while the light one the landscape that has managed to preserve a certain quality. Obviously, the two maps are complementary since the two elements closely dependent.

4.2 Carbon Sequestration Function

The second ecosystem function investigated is the Carbon Storage and Sequestration. estimated by investigating the carbon stock in present land use. Specifically, the carbon stock is valued on the size of 4 primary carbon “pools” defined by the IPCC [29]:

1. Above-ground biomass. All living biomass above the soil including stem, stump, branches, bark, seeds and foliage.
2. Below-ground biomass. All living biomass of live roots. Fine roots of less than (suggested) 2mm diameter are sometimes excluded because these often cannot be distinguished empirically from soil organic matter or litter.
3. Soil organic matter. It includes organic matter in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series.
4. Dead organic matter. This category combines in one section Dead organic matter includes litter as well as

For each of these pools, was estimated the total carbon storage. Considering that is not available a specific database at local level we aggregated different sources.

As required by the InVEST model, a LULC map composed by the single categories of land use cover defined in the DBtop has been created. A selection of LULC categories in the area of the case study was completed also with the table of associated values. In this case study, the impermeable area (buildings, infrastructures, industrial platform), the water system (rivers, lakes, streams) and the desolate and unfertile areas are not considered. Below are listed the input data for InVEST program.

- Current land use/land cover (LULC) map that is the same dataset charged for Habitat Quality function previously presented. A table of LULC classes, containing data on carbon stored in each of the four fundamental pools for each LULC class.

As for the Habitat Quality index, the input file were elaborated in a GIS platform using ArcGis 10.1 release with a high detailed resolution of the raster file (5*5 meters cell size) with LULC code as pixel unit, using the maximum area of pixel as proxy to attribute the value. For the four carbon pool requested by the model the data were collected using different sources. Particularly, some data were provided by Silvia Solaro and Stefano Brenna - ERSAF[5] and the Italian National Inventory of Forests and Forest Carbon Sinks[6] in the second annual report of 2005.

5 http://www.aip-suoli.it/editoria/bollettino/n1-3a05/n1-3a05_07.htm
6 http://www.sian.it/inventarioforestale/jsp/dati_introa.jsp?menu=3

Table 3. Input .csv file

lucode	LULC_name	C_above	C_below	C_soil	C_dead
1	residential	0	0	0	0
122	street	0	0	0	0
14	urban green	10	2	12.4	0.4
2	agricultural	30	6	37	1
3	natural	50	10	65	5
45	water	2	1	3	0

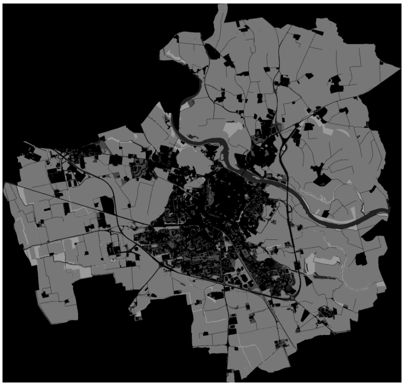

Fig. 2. Carbon sequestration

The output maps consisted of the total amount of carbon currently stored in milligrams as a sum of all carbon pools per grid cell of 5*5 meter. Due to the reliance on LULC data, carbon storage estimates strictly depends on the detailed LULC classification utilized.

4.3 Outputs

Even at preliminary stage, InVEST produces outputs that seem to fits for evaluation of ES at local scale. The two elaborations where enough detailed to support local strategies for planning options management. This means that two of the most important soil function are mapped and evaluated using a specific software. The procedures facilitate a successive multi-criteria analysis [30] should help to produce a Soil Quality Indicator (SQI) [31] [32] [33] necessary to understand if:

- urban transformation occurs on good or bad locations (referring to soil quality);
- how land use change impact with the environmental condition of soil;
- where mitigation, compensation or restoration occur.

Even simplified, the model helps to clearly define an environmental zoning where definition of the green corridors and infrastructures necessary to maintain or restore the quality of open spaces is crucial, and thus planning procedures could be empowered by this tools which give a technical robustness to specific sustainable analysis for planning are requested [34] [35].

This approach can also serve to evaluate the potential recovery of ES after land transformation. The model can support decision making for more sustainable development and is useful for making decisions for selecting lower impact sites [30]. This can significantly contributes to bridge the gap between theories and practices of sustainable town planning using ES indicators as proxies of Soil Quality.

In this preliminary analysis, only two functions were considered in order to test the InVEST model and the database available so it is quite difficult to understand at all how changing parameters of each single variables of input dataset can have significant effect on model's output. Probably a continuous work within the dataset input could enforce such objective. Further, more the program is tested at local scale, more the detail of information augment.

Anyway, it is possible to state that the technical support of the software is crucial to fill the gap between analysis and project of land transformation, its use in the screening phase of local planning, or even in advanced practices of spatial transformation, could produce significant political awareness of soil related function.

This simple consideration could enforce the aim of having significant technical tool that directly influence practices, process and project of land transformation even at the local stage.

5 Conclusion

The InVEST model propose a geo-informatization of different Ecosystem functions in order to determine the baseline services and, subsequently, the potential changes caused primary by land use changes. Each service is modeled separately, so that stacking of services takes place with the combination of model results.

The applications of InVEST can be useful to a wide variety of users, including conservation organizations, government agencies and research centers. Unfortunately, the Author's Guide of the program is delivered and oriented not for who intend to use it as a tool for local strategies of land use planning. Of course, the program can support such use, but all the sources needs to be re-defined, re-selected, and scaled to an expected output with a high degree of precision.

As mentioned, the output strictly depends on the detail of the LULC data and information, a more disaggregation of the different land uses influence the spatialization of the output in the final maps. More than that, the data required are very specific and detailed so their assumptions are often simplified with a margin of uncertainty. This is the principal limit to the InVEST model and, generally, for all the models that work with a large amount of data.

The organization of the input is one of most complex aspect of the model and would be very time consuming and challenging to obtain. This was experimented especially in the Carbon Sequestration function.

Moreover, usually the data needs are very specific and may often require to create new data with different investigations to complete a specified analysis.

By the way, some limitations are also connected with bibliography, especially on practical application, which is quite general or absent even if the time spend to collect the information and data, as well as the expertise beyond what may be gathered from the documentation and bibliography [36].

Even more the environmental databases of sources (climatic, hydrologic, pedologic…) are often collected and restituted at macroscale rather than at microscale. But, as it is broadly confirmed by literature, is the recognition and definition at local scale of ES that can really support policies against land take, preserving natural functions. Especially in context with high administrative fragmentation the local plan can give significant contribute to ES preservation when it take care soil quality on microzones of land. Also some research point out that it is on micro transformation the place where impact of land take on ES is higher. This is why InVEST is just a tool to starting an analysis which need to be refined, articulate, handled with adjustment, even simplified, with adding information, or with a synthesis of results made with multi-layered analysis.

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