Integration in Sustainability Impact Assessment: Meanings, Patterns and Tools[1]

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Draft

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1 Introduction: which integration ?

SIA can be defined as an integrated assessment of social, environmental and economical impacts of projects, plans and policies. As such, it can be considered a response to the call for more integration between environmental, economic and social impact assessment and appraisal. As Lee and Kirkpatrick argue[2]:

"*Since the sustainable development goal has interdependent economic, social and environmental components, it is argued that appraisal procedures and methodologies should use interconnected economic, social and environmental appraisal criteria which are consistent with achieving this goal. This has a bearing on a more general need to strengthen appraisal methods for use at more strategic levels of decision making relating to development policies, plans and programs*".

However, the way integration is used and called for in the literature is not restricted to appraisal methods. Indeed, Scrase and Sheate (2002)[3] found no less than fourteen (14) different meanings for integration in their overview of this literature. They are summarized in the following table (Scrase & Sheate, 2002, 278).

While Scrase and Sheate's overview is invaluable, their classification is not as satisfying because it is not based on a set of clear-cut criteria. For instance, what is the rationale of distinguishing between type E and type F? Or between B and N meanings? Or between G and K, etc.

It seems that the fourteen different meanings could easily be reduced to no more than four general categories of integration: policy, institutional procedural, cognitive and evaluative or normative.

[2]Lee,N and Kirkpatrick, C., "Integrated appraisal, decision making and sustainable development", in Lee, N. and C. Kirkpatrick (eds.), 2000, *Sustainable Development and Integrated Appraisal in a Developing World*. Edward Elgar : Cheltenham, UK and Northampton, MA, USA, pp.1-19, p4.

3 Scrase, J.I. and W.R. Sheate, "Integration and Integrated Approaches to Assessment: What Do They Mean for the Environment?", J. Environ. Policy Plann. 4: 275–294 (2002)

Table 1. Meanings of integration in environmental assessment and governance

Meaning	Main focus	Type of policy learning[a] Level of policy change[b]
A. Integrated information resources	Facts/data	Technical, social Settings
B. Integration of environmental concerns into governance	Environmental values	Conceptual, social, technical Goals, delivery, settings
C. Vertically integrated planning and management	Tiers of governance	Social and technical Delivery, goals
D. Integration across environmental media	Air, land and water	Technical, conceptual, social Settings, delivery, goals
E. Integrated environmental management (regions)	Ecosystems	Conceptual, social, technical Goals, delivery, settings
F. Integrated environmental management (production)	Engineering systems	Technical Settings, delivery
G. Integration of business concerns into governance	Capitalist values	Conceptual Goals, delivery, settings
H. The environment, economy and society	Development values	Conceptual, social Delivery, settings
I. Integration across policy domains	Functions of governance	Technical, social Settings and delivery
J. Integrated environmental–economic modelling	Computer models	Technical Settings, delivery
K. Integration of stakeholders into governance	Participation	Social, conceptual Delivery, settings, goals
L. Integration among assessment tools	Methodologies/procedures	Technical Settings, delivery
M. Integration of equity concerns into governance	Equity/socialist values	Conceptual Goals, delivery, settings
N. Integration of assessment into governance	Decision/policy context	Social, technical Delivery, settings

[a] Based on definitions in Glasbergen (1996) and Fiorino (2001). Ordering indicates importance to the meaning.
[b] Based on definitions in Hall (1993). Ordering indicates importance to the meaning.

1.1 Policy integration

Policy integration "*concerns the management of cross-cutting issues in policy-making that transcend the boundaries of established policy fields, which often do not correspond to the institutional responsibilities of individual departments...Integrated policy-making refers to both horizontal sectoral integration (between different departments and./or professions in public authorities) and vertical inter-governmental integration in policy-making (between different tiers of government) or both* ".[4]

Scrase and Sheate explicitly address vertical integration under their C meaning ("Vertically integrated planning and management"). Horizontal integration is addressed with the E, F and I meanings.

1.2 Institutional integration

By "institutional" or "procedural integration" we are referring to the way sustainable impact assessment is taken into account in the policy-making process.

This corresponds to Scrase and Sheate's B and N conceptions of integration, the former referring to the legal obligation to carry on impact assessments (environmental or

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[4] Meijers, E. and D.Stead, "Policy integration: what does it mean and how can it be achieved? A multi-disciplinary review", 2004 Berlin Conference on the Human Dimensions of Global Environmental Change: Greening of Policies – Interlinkages and Policy Integration.

others) of some policies, plans or programs while the latter concern their procedural integration in the policy-making process. One historical landmark in this respect, even if limited to the environment, is the US National Environmental Policy Act of 1969 that established the procedure of Environmental Impact Assessment (EIA).

Two more recent examples of more comprehensive institutional integration in policy-making are the European Union's Directive 2001/42/EC, known as the "SEA Directive" and the UNECE's SEA protocol[5].

1.3 Cognitive integration

This means integration of facts, data, problems and concerns. It covers the A, D, E, H, J, and L meanings.

Under the D meaning ("integration across environmental media"), Scrase and Sheate emphasize the need to acknowledge the interconnectedness of the various environmental media (air, water and land) and to take it into account in environmental regulations. The E ("Integrated environmental management of regions") and F ("Integrated environmental management of production") meanings are based on similar concepts, the former taking into account the ecological relationships across space, the latter being a concretisation of D meaning in production patterns. As example of lack of data integration, Lund and Iremonger (2000) pinpoint the use of statistical and forestry divisions of the United Nations Food and Agricultural Organization to define forested and agricultural land differently therefore leading to conflicting data sets (Lund and Iremonger,2000). These kinds of integration amount to a widening of the concerns and of the information basis of the decision-maker, be it public or private.

Integration of environment, economy and society (meaning H) takes us still one step further with concerns that are not limited to the environmental domain but takes into account the economy and society as well. Concerning the latter, Scrase and Sheate fear that: "*The limitations of time and resources going into any assessment mean that there will necessarily be a loss of depth in consideration of the environment if social and economic objectives and criteria are considered simultaneously. For example, there may be a neglect of environmental baseline studies, and a dependence on expert judgment rather than deeper analysis or wider participation*"(283). Fully agreeing with a strong conception of sustainability, they think that this kind of integration could too much easily leads to trade-off between the environment and economic gains at the expense of the former.

We obviously include in cognitive integration, "integrated environmental-economic modelling" (meaning 'J' in Scrase and Sheate paper), while pointing out the somewhat restrictive definition they give of it, as" computer models that combine natural science and economic optimisation modules"(284). It is true that most integrated assessment models in climate policy are of the optimisation kind but one find also macro-econometric, computable general equilibrium and input-output models in the field.

The L meaning "Integration among assessment tools" also takes place in this category.

[5] For a discussion of these two institutional landmarks, see Therivel (2004), especially the third chapter.

1.4 Evaluative or normative integration

Evaluative integration refers to the way different values standpoints and perspectives are integrated in the decision-making process and outcome. Meanings G, K and M fit more or less in this category. Meaning G ("Integration of business concerns into governance") refers explicitly to possible value conflict between environmental and business. As an example of how the concept of integration can endanger environmental concerns, Scrase and Sheate quote a standpoint from the Union of Industrial and Employers Confederation of Europe (UNICE, 2001, 6)[6]:

"*the integration process must take due consideration of the three pillars of sustainable development, and in particular the requirement of strengthened competitiveness, given the critical importance of the latter for sustainable development"*.[7]

Meaning K ("Integration of stakeholders into governance") could also be related to cognitive integration insofar as stakeholders' participation is instrumental also in providing factual information (local knowledge) indispensable for sound policy-making, as Scrase and Sheate rightly acknowledge (284):

"*there is the instrumental view that input from a more diverse range of actors will improve decisions by introducing options or evaluation criteria that might otherwise be overlooked. In particular, people living in a locality (or working in an industry) that may be affected often hold valuable environmental knowledge that can be used to improve decisions."*

However, it is mostly as a condition for the free expression of the pluralism of values that stakeholders' participation is praised even if:

"*In practice, stakeholder participation often amounts to little more than consultation. This informs stakeholders of policy intentions, and provides an opportunity to comment. This may serve to legitimate decisions, while the process has not in fact been conducted in a way that yields any of the benefits discussed above.* (285)

It could be argued that integration of stakeholders in the policy-making process and therefore also in the sustainability assessment is so important that it should be considered as a fully-fledged kind of integration along with the institutional, cognitive and evaluative ones. On the other hand, as a condition for real integration in the three above-mentioned ways, it is perhaps better to refrain making it a separate category.

Finally, meaning M ("Integration of equity concerns into governance") is obviously concerned with the integration of ethical values in policy-making.

In what follows, we deal only with cognitive and normative integration. That is, we suppose achieved a level of policy integration such that sustainable development can be plainly addressed.

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[6] UNICE (Union of Industrial and Employers' Confederations of Europe). 2001b. *European Industry's Views on EU Environmental Policy-Making for Sustainable Development*. http://www.unice.org [28 February 2002].

[7] Emphasis is from Scrase and Sheate.

2 Cognitive and evaluative integration in SIA

2.1 Cognitive and normative aspects of decision-making

The most convenient framework for discussing SIA from a methodological point of view is what is known in the ecological economic community as the multi-criteria decision-making model,[8] which is actually a reformulation of the old-fashioned rational decision model. We will use it here for helping articulate and organize our discussions.

As exposed here, the framework looks probably more linear and straightjacket than it is in real political life. The real decision-making process is not like a succession of waterfalls, or, if so, waterfalls such as the ones in the famous Escher's painting where water seems going up and down the staircases. For instance, there will be back and forth going between criteria and alternatives; preliminary impact assessment[9] leading to definition of new alternatives and so on. Indeed, this consideration is very important when it comes to define the role of impact assessment. Actually, one of the most useful outcome of assessment is precisely to suggest new ways, more environmentally efficient and socially fair to reach the goal. Environmental Impact Assessment, for example, is often criticized precisely for coming too late in the decision process and being therefore helpless in finding and evaluating alternatives[10].

It is somewhat illusory to conceive of actual political decision-making as a totally – or even mainly – rational operation. A careful examination of real practices contradicts this platonic vision[11]. However, I think this argument is irrelevant in the context of SIA because if policies are to be evaluated, it can only be on a rational basis, which is in terms of objectives, criteria, anticipated impacts and their relationships. Thus, whatever their real genesis, they have to be accountable in a rational framework.

Admittedly, socio-economical policy-making, and even more, sustainable development policy-making, is a special kind of decision-making. First of all, and contrary to what happens in "normal" decision-making situations, the objectives here are not given beforehand. On the contrary, the very definition of the goals and objectives is an important part of the decision problem itself, and of the definition of sustainable development. Next, there is not just one decision-maker but a plurality of decision-makers each with her own preferences, goals, expectations and beliefs. Finally, the assessment of consequences as well as the evaluation of costs and benefits is many orders of magnitude more difficult in

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[8] See Funtowicz, O., Martinez-Alier, J., Munda, G. and Ravetz, J.,"Multicriteria-based environmental policy », in Abaza,H. and Baranzini, A.,eds. (2002), *Implementing Sustainable Development. Integrated Assessment and Participatory Decision-Making Process*, UNEP, Edward Elgar : Cheltenham, UK and Northampton, Mass. USA, pp. 53-78.

[9] At least if one understands SDIAPP as "objective-led impact assessment" (Pope, J. Annandale, D., Morrisson-Saunders, A., "Conceptualising Sustainability Assessment", *Environmental Impact Assessment Review*, 24 (2004), 595-616.

[10] Steinemann, A., "Improving alternatives for environmental impact assessment", *EIA Rev*. 21-1, 2001, 3-21.

[11] See, for example, D.Stone, 2002, *Policy Paradox. The Art of Political Decision Making*, New-York, London : Norton & Company.

SD problems than in any usual business. Therefore, SD has both substantive and procedural consequences for the policy-making process. As indicated in the project proposal, these consequences can be summarized by the concept of integration.

Briefly, decision-making as formulated in the multi-criteria framework consists in:

- an objective (O);
- a set A = [a_1,a_2,….a_n] of n alternative ways to reach the objective;
- a set C = [c_1,c_2…c_m] of m evaluation criteria (sometimes defined as sub-objectives) on which to assess the various alternatives;
- a set (perhaps empty) W = [w_1,w_2;…w_m] of m importance weights for each criterion;
- an evaluation function f such that O = f(W*C*Ai).

In complex decision-problem, more often than not, every criterion will be, in turn, broken down in a subset of (sub)criteria, possibly with its own set of (sub)weights.

The decision problem may thus be represented as a hierarchy with O at the top, A at the bottom and several levels of criteria in between, as in the figure 1 below.

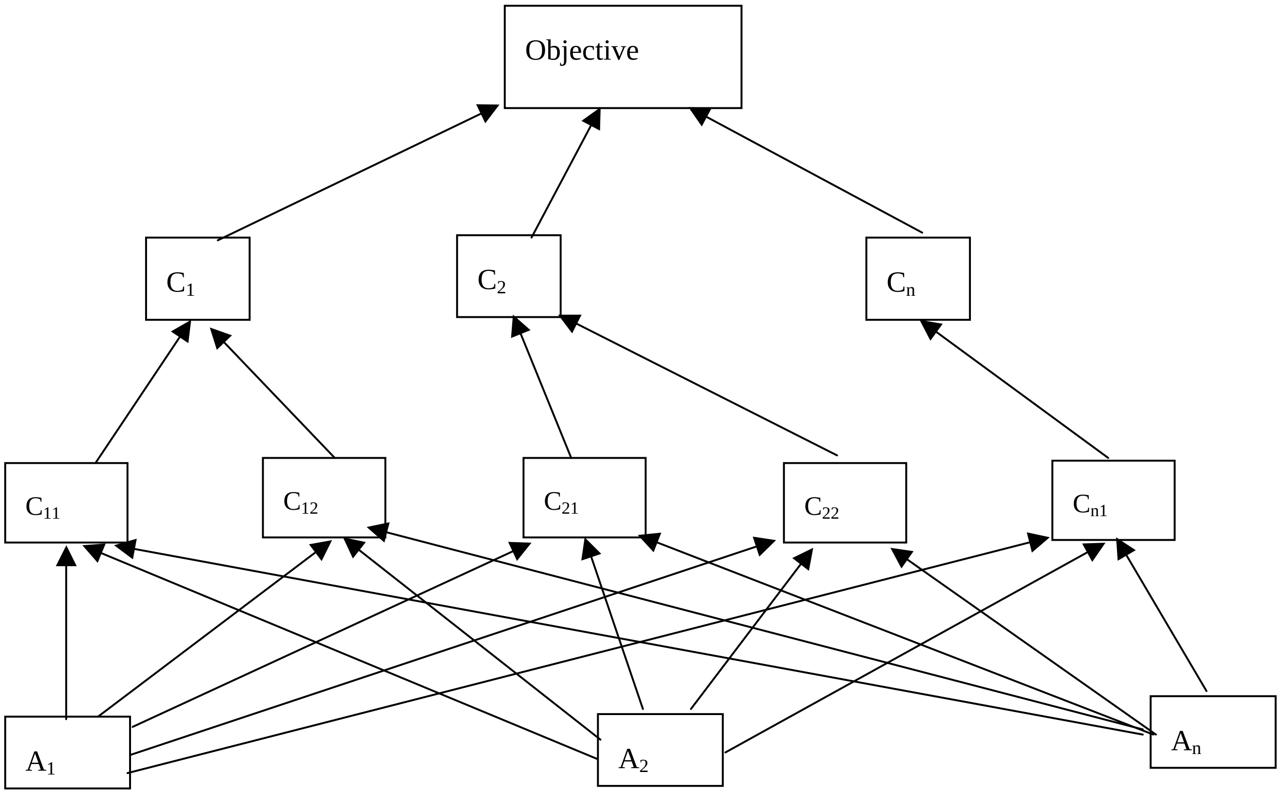

Figure 1. The multi-criteria decision making model

Every alternative is assessed against the various criteria, leading to the construction of what is called an impact matrix (see Table 1).

Table 1. The Impact Matrix in multi-criteria decision-making framework.

Criteria	*Weights*	*Alternatives*			
		a_1	a_2	.	a_n
c_1	w_1	$c_1 w_1 a_1$	$c_1 w_2 a_2$	.	$c_1 w_n a_n$
c_2	w_2	$c_2 w_2 a_1$	$c_2 w_2 a_2$	.	$c_2 w_2 a_n$
.	.	.	.	.	.
c_m	w_m	$c_m w_m a_1$	$c_m w_m a_2$	.	$c_m w_m a_n$
f		$f(c.\ w.\ a_1)$	$f(c.\ w.\ a_2)$	.	$f(c.\ w.\ a_n)$

In multi-attribute utility (or value) theory (MAUT) or in cost-benefit analysis, information is then aggregated with the help of a specified function (usually a simple summation or product but it can also be something more sophisticated). It is not the case with multi-criteria models based on the outranking methodology. We will come back to this in the section devoted to evaluative integration..

In the public policy context, the objective O is the main goal of the intended program or policy and the various alternatives [A] may refer to alternative measures or policies[12].

As for the criteria, they may be also interpreted as:

- sub-objectives or intermediate objectives;
- constraints (budget, human resources, timetable…);
- conditions of success.

The decision-making process itself consists in:

1. Setting the objective (E);
2. Identifying the criteria (I);
3. Weighing them (E);
4. Identifying the alternatives (I);
5. Assessing every alternative with respect to each criterion, that is filling the impact matrix with partial scores) (I);
6. Aggregating the partial scores for each alternative giving an overall evaluation (I+E);
7. Choosing the most preferred one (E).

These different stages may be classified as (mainly) informative or (mainly) evaluative. This is the meaning of the E or I between brackets after each item in the enumeration here above. It is patent that the overall process is both evaluative and informative, that is, it mixes axiological, normative and factual propositions.

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[12] Or various possible “states of the world” in which the policy is going to take place.

- The first step is generally the outcome of a previous evaluation of past decisions and policies, especially with respect to their impact.

- The second step - identifying the criteria to be used in the assessment -, is mainly evaluative even if it can include some important purely cognitive (informative) elements, relating, for instance, to the factors of success or failure of the intended policy.

- The third step (weighing the criteria), is probably one the touchiest from a political point of view. It raises the very difficult problem of comparing sometimes totally different (even incommensurable) subject matters and weighing conflicting human and social interests, as is often the case in sustainable development context. It supposes also that answers can be given to the problem of the inevitable trade-offs between the various criteria. In a public policy context, there can be no purely scientific or a priori way of solving these problems. It is sometimes argued that a universally accepted and fully operational theory of justice could give rational answers to such questions. But one can be sceptical about this and, anyway, there is no such theory at the moment. In the meantime, only procedural rules and collaborative (participative) mechanisms can offer some guarantee of fairness in weighing and "trading" the various criteria.

- The fourth step is mainly informative (even if constrained by normative consideration which rule out, for ethical reasons, some policy instruments). Often, there is only one alternative to be considered, which is then called a baseline that can be, but not necessarily the statu quo ante.

- The fifth stage is purely cognitive. It consists in "predicting" the likely impacts of the various alternatives from each selected criterion point of view (i.e. for each sub-goal, constraint and/or prospect of success or failure). This is the core business of *ex ante* "impact assessment" strictly speaking. But beware: purely cognitive doesn't mean only scientific. Local and "personal" knowledge can be as important an input here that scientific statements.

The distinction between cognitive and evaluative integration is helpful in providing a convenient basis for a – however crude- first taxonomy of the various tools and methods found in the impact assessment literature. Handbooks of Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), Integrated Assessment (IA), etc., are full of references to methods and techniques such as: checklists, life-cycle analysis, focus groups, system models, matrix methods, cost-benefit analysis, optimisation, multi-criteria analysis, input-output analysis, Computable General Equilibrium models (CGE), risk assessment, etc. However, it is very difficult to find a rationale to the way they are presented and organised. More often than not one is facing unordered lists, mixing cognitive and evaluative tools, data acquisition and data utilisation methods, qualitative and quantitative methodologies, simulation and optimisation, objective and subjective methodologies, causal and non-causal approaches, etc.

One will find in figure 2 a tentative[13] taxonomy of several methods[14] viewed from a integrative standpoint and based on the distinction between cognitive and normative integration.

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[13] Tentative insofar as it doesn't pretend to be exhaustive or the most accurate.

[14] We include in this overview some tools that are rarely -if any- mentioned in the environmental assessment literature but that we believe should be part of the assessment toolbox. We have in mind here (fuzzy) cognitive maps and, especially, Bayesian networks.

2.2 Patterns and tools of cognitive integration

Cognitive integration consists in putting together the various kinds and pieces of information necessary to take a well-informed decision. This is, a priori, not restricted to of scientific knowledge, even if other sources of information are often omitted in the literature. Take, for instance, the definition of integrated assessment by Rotmans and Dowlatabadi[15] :

"*In general, integrated assessment can be defined as an interdisciplinary process of combining, interpreting and communicating knowledge from diverse scientific disciplines in such a way that the whole cause-effect chain of a problem can be evaluated from a synoptic perspective.*" It deals only with scientific knowledge and leaves no room for other kinds of non-scientific information that are sometimes necessary for sound policy-making. This can be explained by the fact that most integrated assessment exercises occur in the climate change and climate policy domain where non-scientific knowledge is less relevant but it is certainly not the case in other domains such as land-use, mobility, agriculture, etc.

Not only does SIA need to integrate scientific and non-scientific knowledge, it need also integrate lack of knowledge and other sources of uncertainty[16], as well as different time and space scales.[17]

Indeed, if one is to take seriously N.Lee argument about the need to "*bridge the gap between theory and practice in integrated assessment*",[18] ("*Sustainability Impact Assessment (SIA)…assumes that the economic, environmental and social impacts are to be assessed according to the criteria consistent with the promotion of sustainable development*") then the candidate methods and tools must themselves be assessed against the following criteria:

1. To what extent do they really help in integrating various disciplinary knowledge and economic, social and environmental concerns?

2. What level of stakeholders' participation do they provide for?

3. How do they cope with uncertainty?

4. In what extent do they integrate long term and short term perspectives?

5. Do they provide for local and global interactions?

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15 J. Rotmans and H. Dowlatabadi, Integrated assessment of climate change: Evaluation of methods and strategies, in: *Human Choices and Climate Change: A State of the Art Report* (Batelle Pacific Northwest Laboratories, Washington, DC, 1997).

16 Rotmans, J. and M.B.A. van Asselt, "Uncertainty in integrated assessment modeling: A labyrinthic path", *Integrated Assessment* (2001) **2**:43-55.

17 See Boulanger, P.-M and T. Bréchet, 2003, "Models for sustainable development policy-making: state of the art and perspectives", 2003, Institut pour un Développement Durable, Ottignies. http://www.iddweb.be.

18 Lee,N.,2003, "Bridging the gap between theory and practice in integrated assessment", EU,Workshop 3 "Towards Regional Sustainable Development: Evaluation Methods and Tools", June 2003, Manchester.

6. For what kind of policy are they especially relevant?

7. Do they match an adequate conception of sustainable development?

The methods listed in figure 2 under the heading "cognitive integration" have been regrouped in three mains classes: geographical, causal and accounting. The classification is partly based on the distinction proposed in the OECD report "Sustainable Development: Critical issues" between analytical and accounting frameworks[19] for integration of economical, environmental and social variables.

OECD doesn't give a precise definition of analytical frameworks but gives only two examples of such framework: the PSR, DSR, DPSIR approach and the "resource-outcome indicators" approach.

- The former is a kind of general causal model of the relationships between the environment, the economy and policy. It has proved very efficient in that domains but it is considered less suited to the social and distributives aspects of sustainable development.

- The "resource-outcome indicators" approach focus on the various kind of assets (resources) necessary to meet the needs of future generations and the way these needs are met today (outcomes). It is very close to the definition of SD in terms of the four capital stocks (man-made, natural, human and social). If the DPSIR framework is basically a causal model, the resource-outcome is basically a stock-flow model. It is to be noticed that variables (indicators) in causal as in stock-flow models refer to systems, not to agents.

On the contrary, accounting frameworks are built on exchange relations or transactions between *agents*: industries, households, and institutions[20] as pictured in the Social Accounting Matrix (SAM), an extension of national economic accounts stated in matrix form. Another recent extension of national economic accounts, NAMEA (for National Accounting Matrix with Environmental Additions), allows also integration of natural resources, wastes and pollutions in the common framework. Actually, combining a SAM and a NEMEA opens the way to fully economic, social and environmental integration. The only example of such schemes is the SESAME[21] (System of Economic and Social Accounting Matrices including Extensions) framework developed in Netherlands. In SESAME, integration of environmental, economical and social variables is achieved in a consistent manner while expressing each sector in its "natural" units (money, physical units and time units).

The methods and tools listed beneath the "causal" heading can be seen as operationalisation of analytical models such as causal (DPSIR, for example) or stock-

[19] OECD, 2001, *Sustainable Development – Critical Issues*, p.62.

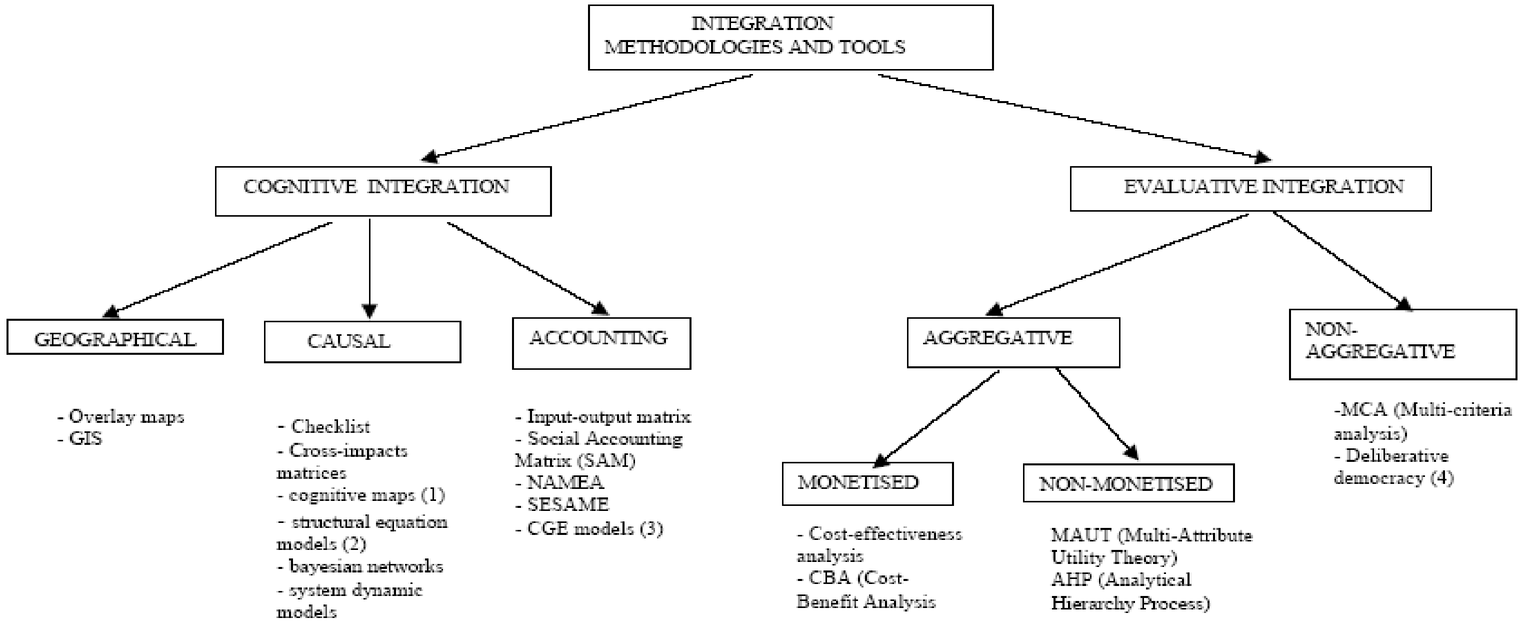
[20] If nature is introduced as is the case with the NAMEA (National Accounting Matrix including Environmental Accounts) it is on the model of the economical agent delivering its production to others agents (industries, households..) and being serviced by them (as waste).

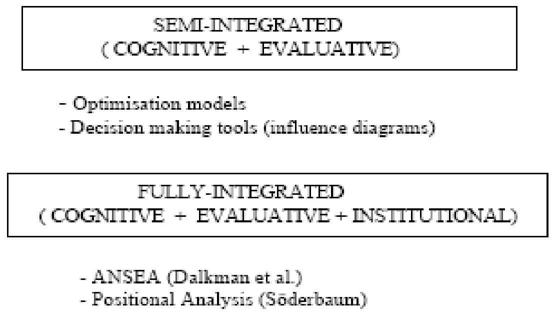
[21] See for example, Timmerman, J. and P. van de Ven, 2000. "The SAM and SESAME in the Netherlands: A modular Approach" in United Nations, ed.,*Handbook of National Accounting*, Studies in Methods, Series F, N°75/Vol 2., pp 309-351. See also : F. Duchin,, 1998, *Structural Economics. Measuring Change in Technology, Lifestyles and the Environment*. Washington.D.C.: Island Press.

flows models of environment, society and economy. Indeed, structural equation models or Bayesian networks models suppose a cause-effect relationship between the variables. In system dynamics models, the dynamic behaviour of the system by the network (structure) of interlinked positive and negative feedbacks loops between stocks (levels) and flow variables (rates).

With geographical methods, integration results from the superposition of representations of different point of views (as successive layers) on a topographical map of the concerned area.. Overlay maps and GIS deserves a special treatment as very powerful integration techniques provided that the decision has physical impacts on land uses and landscape, which is far from always true.

The methods and tools are - rather loosely - ranked from the less demanding to the more demanding in terms of data requirements and/or skills. For instance, checklist is less demanding than cross-impact matrices, overlays maps less than full GIS application, etc. The less demanding will be preferred at the screening stage of the process or in case of lightweight assessments. However, beyond this consideration, it is very difficult to say which integration method is to be preferred. It depends heavily on the kind of policy or program to assess. Indeed, each has its strengths and weaknesses. For instance, Bayesian networks are very good in risk assessment, contrary to accounting methods. Social accounting matrices are probably the best way to explore the distributive impacts of macro-economic policies but are very weak when it comes to long-term consideration. Overlay and GIS methods are priceless in assessing land-use policies but inadequate for trade policies, for example, etc. Moreover, they are not necessarily exclusive one of the other. For example, input-output matrices and GIS are frequently associated in land-use and transport models.





(1) Cognitive maps as well as interpretive structural models can be quantitated either in system dynamics models, in probabilistic (bayesian) networks or in structural equations models.
(2) Structural equation models, bayesian networks and system dynamics models are viewed here as operationalisation of causal or stock-flows conceptual frameworks.
(3) CGE models are often associated with I-O and SAM matrices on which they are calibrated.
(4) Citizens' jurys, consensus conferencies, etc., are well-known methods of deliberative democracy.

2.2.1 Causal tools

2.2.1.1 Checklists

The most usual tool for impact identification (or criteria selection) is the **checklist**, an ordered list of items to look at, such as the one supplied by the UE Commission in its "Handbook for Impact Assessment in the Commission"(Annexe 6), reproduced here as Annexe 1.

At best, the items are (loosely) ordered following some conception (or conceptual model) of sustainable development. Usually, it is the "Triple Bottom Line" (TBL) or "Three pillar" vision, as with the UE handbook checklist. There also a few checklists, mainly in the environmental domain, based on the DPSIR (Drive-Pressure-State-Impact-Response) framework. As such they can be considered the "ground zero" of analytical integration. They are useful because they allow a systematic consideration of all possible impacts. However they are unable to identify indirect effects or interactions between impacts. This is where interaction matrices come on stage.

*2.2.1.2 Checklist * checklist = interaction matrix*

Matrices are very easy way to portray the express the relation between two sets of variables. Basically, if there is a relation between a row variable **i** and column variable **j**, then the cell **ij** of the matrix is non-empty. What is exactly in the cell depends on the frame in which the relationship is described. Generally, in impact assessment, we want to express that the row variable *influence* or *cause* the column variable. The cell can hold one or several information relative to the kind of influence, its sign (positive or negative influence), its magnitude, its significance, etc.

For example, in a "Leopold Matrix" a cell holds two information, one on the strength of the relation, another on its significance, both expressed in a scale from 1 to 10. A Saratoga matrix holds 4 information per cell.

Cell in Leopold Matrix *Cell in Saratoga Matrix*

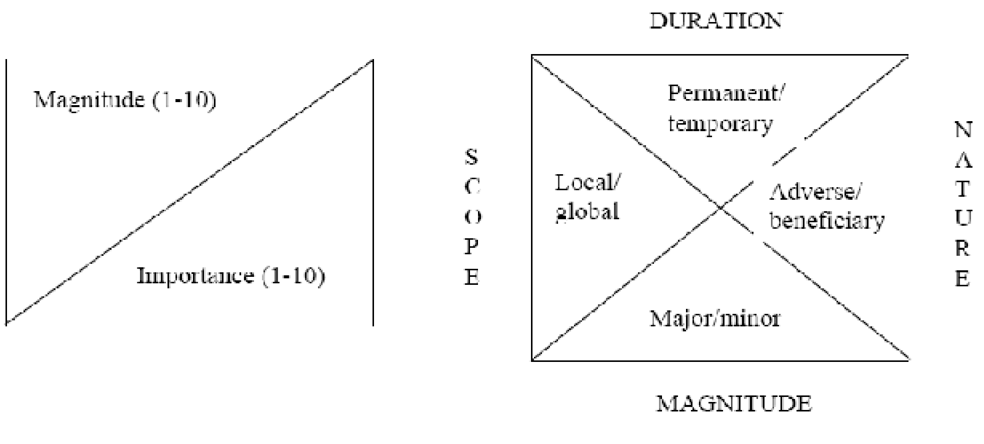


Figure 3. Examples of cells in cross-impact matrices

A matrix can be considered as a crossing between two checklists (or one checklist with itself). For instance, a Leopold matrix crosses a list of actions with a list of environmental factors. Many kinds of matrices have been developed in environmental impact assessments. One can consult Barrow (1997) for information on component interaction matrix, minimum link matrix, disruption matrix, goals achievement matrix, Moore impact matrix, compatibility matrix, etc. Binary matrices are square matrices with the same variables in row and in columns. Boolean matrices are binary relations matrices where the cells can only hold 2 values: 0 or 1. Despite their simplicity, Boolean matrices can help in analysing the "structural complexity" of the model, and identifying indirect 'nth' order relations between the variables. See for example table 2 that shows the direct causal link between variables.

Table 2. Matrix **A** of direct influences between variables [a,b,c,d,e,f,g,h,i].

	a	b	c	d	e	f	g	h	i
a		1	1						
b				1	1				
c						1			
d							1		
e								1	1
f									1
g									
h									
i									

The direct links are the following:{a-b, a-c, b-d, b-e, c-f, d-g, e-h, e-i, f-i). But, for instance, d is influenced by b and therefore, b indirectly influence g, by its link with a direct cause of g. If we multiply the matrix by itself, that is if we calculate $\mathbf{A}^2$, we can see the first-order indirect links between the variables as in table 3.

Table 3. Matrix $\mathbf{A}^2$ of first-order indirect influences between variables [*a,b,c,d,e,f,g,h,i*].

	a	b	c	d	e	f	g	h	i
a				1	1	1			
b							1	1	1
c									1
d									
e									
f									
g									
h									
i									

First-order indirect links are: {*a-d, a-e, a-f, b-g, b-h, b-i, c*-i}. One can see that variable *a*, which directly influences *b* and *c*, influences also indirectly *d*, *e* and *f*.

$\mathbf{A}^3$ gives second-order indirect links. In this case it consists in: {*a-g, a-h, a-i*). Of course, it is most likely that the strength of a direct influence is bigger than that of a first-order indirect one, itself bigger than the second-order, and so on.

After a finite number of matrix multiplication, there is no more change in the results (no more indirect effects). Even if it is not the case with the above example, indirect links can be discovered between a variable and itself. It indicates a feedback loop in the causal structure of the system.

It is also possible to express in a single matrix the sum of direct and indirect links. For this, it is first necessary to normalise the initial matrix **A** of direct links by multiplying each if its element by a constant λ calculated as the reciprocal of the largest row sum of **A**.

$$\mathbf{X} = \lambda\ \mathbf{A}$$

The infinite series of direct and indirect effects has a finite sum given by:

$$\mathbf{X^*} = \mathbf{X} + \mathbf{X}^2 + \mathbf{X}^3 + \ldots = \mathbf{X}(\mathbf{I}-\mathbf{X})^{-1}$$

We will meet this expression again later when speaking of Leontief matrices.

Methods such as “Interpretive Structural Modelling”[22] or MICMAC[23]are based on these properties as well as the “component interaction matrix” developed by Environment Canada.

Table 4 shows a cross-impact matrix from Chan & Huang[24] (2004). The impacts are scaled on a 0-3 scale. **AS** in table …refers to the *outdegree* of the row variables, which is the row sum of their absolute values. It measures the cumulative strengths of connections (aij) exiting the variables. Inversely, the *indegree* (**PS** in table…) of a variable is the column sum of its absolute values. It measures the cumulative strength of variables entering it. The most influencing variables have the highest outdegree – they can be called driving variables - while the most dependent (the driven ones) have the highest indegree. Here again, it is possible to uncover high order (indirect) effects by raising the matrix to its successive power. At every iteration, one computes the new rows and columns total, giving a new ranking of the variables on causal power and /or dependency. However, usually, after the fourth or fifth matrix multiplication, the ranking doesn’t change anymore (it stabilises itself). It is to be noted that Chan & Huang doesn’t look for higher order effects. On the other hand, they compute a couple of indexes such as the ratio and the product between the column total and the row total of the variables.

Table 4. An example of cross-impact matrix

2.2.1.3 Matrix + directed graph (digraph) = cognitive (or causal) map

[22] Warfield, J.N. (1976), *Societal Systems: Planning, policy and complexity*, New York : Wiley.

[23] Godet, M., (1997), *Traité de prospective stratégique.* Paris : Dunod.

[24] Shih-Liang Chan, Shu-Li Huang, « A systems approach for the development of a sustainable community—the application of the sensitivity model (SM) »*Journal of Environmental Management*, 72 (2004) 133–147

	Effect of ↓ on →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	AS[1]	P[2]
1	Canals		3	1	3	2	2	3	3	1	2	0	1	0	3	0	0	0	0	2	2	0	0	2	1	1	3	35	1330
2	Cultural activity	3		2	1	2	2	1	1	2	1	0	1	1	3	2	1	1	1	2	2	2	1	2	1	1	3	39	1911
3	Tourism crops	0	1		1	3	2	1	3	3	1	0	0	3	2	2	2	2	1	1	1	1	1	0	2	1	3	37	1554
4	Hiking trails	3	3	1		2	1	1	2	0	2	1	1	1	2	3	2	1	3	2	1	2	1	1	2	1	2	41	1107
5	Local industry	2	2	3	0		2	0	1	3	1	0	0	3	2	3	2	0	1	1	2	1	1	2	1	2	1	36	1728
6	Marketing promotion	2	2	3	0	2		0	1	3	1	1	1	2	3	1	2	2	2	1	2	1	1	1	2	2	3	41	1763
7	Irrigation resource	1	0	2	1	1	0		3	1	2	1	2	0	0	0	0	0	1	1	1	1	2	2	1	2	1	26	572
8	Agriculture	3	1	2	1	2	2	3		2	3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	2	2	42	1302
9	Competition	1	2	1	0	2	2	2	3		0	0	1	2	2	1	1	1	1	1	1	1	1	1	1	2	3	33	1221
10	Water pollution	3	2	2	0	2	2	3	2	2		2	2	1	1	0	0	0	3	1	1	1	2	2	1	1	3	39	1131
11	Waste treatment	3	1	0	1	1	1	2	2	2	3		3	1	1	0	0	0	3	1	1	2	2	1	2	1	2	36	828
12	Recycling	2	1	1	1	1	1	2	2	2	3	2		0	0	0	0	0	1	1	1	2	1	1	2	1	1	29	783
13	Employment	1	2	3	0	2	1	0	2	3	0	0	0		2	1	0	1	0	1	2	2	0	1	2	1	2	29	783
14	Culture industry	2	3	2	1	3	2	1	2	2	1	1	1	2		2	2	2	2	1	3	2	1	1	2	1	3	45	2025
15	Tourist turbulence	1	3	3	2	2	3	0	0	1	0	2	1	1	2		3	3	2	1	2	1	1	1	1	1	2	39	1248
16	Traffic congestion	0	3	0	1	2	0	0	0	0	0	0	0	0	2	3		3	0	1	3	0	3	1	0	0	3	25	575
17	Local Transportation	1	2	1	2	2	2	0	0	0	0	0	0	1	2	3	3		1	1	1	1	2	0	0	2	2	29	667
18	Accessibility to water resource	0	1	0	0	0	2	0	0	0	2	0	0	0	1	2	1	2		3	2	3	2	0	1	2	3	27	999
19	Infrastructure	3	2	2	3	2	1	0	0	1	1	1	0	0	1	1	0	1	2		2	2	1	0	1	2	3	32	1152
20	Community conscience	1	3	2	2	3	3	0	0	2	0	2	2	2	3	1	0	0	2	2		2	2	2	2	3	3	44	2024
21	Environment quality	1	2	1	1	0	2	0	1	2	2	2	2	0	2	1	0	0	3	2	3		2	1	1	2	3	36	1368
22	Local security	0	1	1	0	2	1	0	0	1	1	0	1	1	2	1	1	1	1	1	3	2		1	2	1	2	27	918
23	Local governance	0	2	2	0	3	2	0	0	1	0	1	2	1	2	0	0	0	1	2	3	3	2		2	1	2	32	896
24	Education inputs	2	3	3	1	3	3	2	2	1	2	3	3	1	2	0	0	0	1	1	2	1	2	3		2	3	46	1656
25	Dependence on imported resource	3	1	2	2	1	2	1	1	2	1	2	1	1	1	2	2	2	1	2	1	2	2	1	3		2	41	1558
26	Community image	0	3	2	3	3	2	0	0	0	0	0	0	1	2	1	0	0	3	3	3	2	0	0	2	3		33	1980
	PS[3]	38	49	42	27	48	43	22	31	37	29	23	27	27	45	32	23	23	37	36	46	38	34	28	36	38	60		
	Q[4]	92	80	88	152	75	95	118	135	89	134	157	107	107	100	122	109	126	73	89	96	95	79	114	128	108	55		

Note: 1. Summation of rows, 2. Product of row sum(AS) and column sum(PS), 3.Summation of columns, 4. Quotient of row sum(AS) and column sum(PS) × 100.

Cognitive maps have been introduced in 1948 by the psychologist Tolman (1948) in his paper entitled *cognitive maps in rats and men* as mental models (*belief systems*) of the way animals - including men - structure their environment. The basic idea is that animals have mental representation of their environment that can be pictured as directed graph with nodes referring to events or objects in the environment and the arcs between them referring to the (perceived) relationships between them. However, it is the political scientist Robert Axelrod (not to be confused with the Robert Axelrod who wrote *The evolution of cooperation*) who drew attention to the potential of cognitive mapping in his *Structure of Decision – The cognitive maps of political elites* (1976).

Cognitive or causal maps represents causal (or influence) relationships between concepts, events or more generally variables as nodes in a directed graph with edges or arrows between nodes indicating the presence of a (causal) link between the source of the arrow (node ***a***) and its destination (node ***b***). The edges can be signed. A positive arrow from node ***a*** to node ***b*** means that ***a*** reinforces ***b***, that an increase of node ***a*** will cause an increase of ***b***; a negative arrow that an increase of ***a*** will cause a decrease in ***b***. Any digraph with ***n*** nodes can be associated to a (square) matrix of dimension ***n***, called its adjacency matrix or connection matrix. For instance, the table 5 matrix is an exact representation of the digraph of figure 4, a schematic and incomplete representation of the greenhouse effect[25].

[25] From Ford, A., 1999, *Modeling the Environment. An Introduction to System Dynamics Modeling of Environmental Systems*. Island Press : Washington D.C.

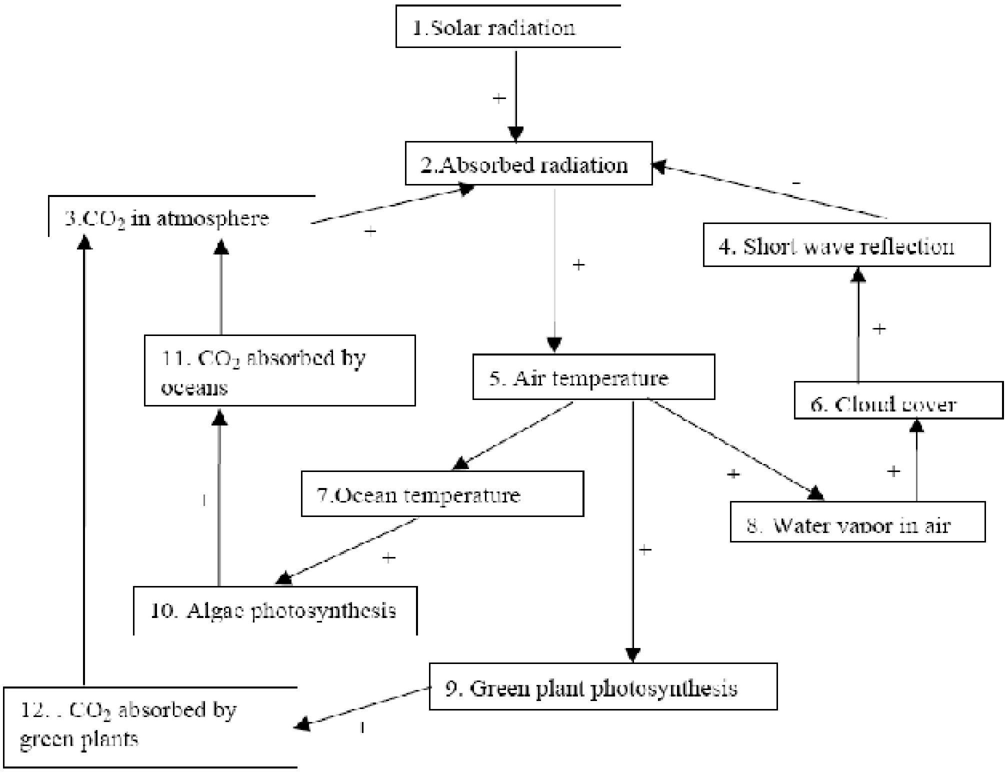


Figure 4. Cognitive map of the (simplified) greenhouse effect

The adjacency or connection matrix associated with the above figure is shown in table 5.

Table 5. Connection matrix of the cognitive map of Figure 3.

	1	2	3	4	5	6	7	8	9	10	11	12	Σ
1		+											1
2					+								1
3		+											1
4		+											1
5							+	+	+				3
6				+									1
7										+			1
8						+							1
9												+	1
10											-		1
11			-										1
12			-										1
Σ	1	3	2	1	1	1	1	1	1	1	1	1	

The table is to be read as follow: a sign (+ or -) in cell ‘ij’ means that the ‘i’variable is influencing the ‘j’ variable. Recall: the value in the last column gives the number of variables influenced by the row variable (*outdegree*). Inversely, the value in last row shows how many variables influence the column variable (*indegree*). The most driving variable in table 2 is the variable 5 (Air temperature) while the most driven are the variables 2 (Absorbed radiation) and 3 (CO_2 in atmosphere). However these are only the first order influence. As explained above, by raising the matrix in table 2 to its successive powers (2,3,4…), it is possible to uncover indirect influences between variables and computing higher order in- and outdegrees.

Graphs such as the one in figure 4 can also be analyzed in term of their dynamic properties provided they can be interpreted as a dynamical system. It is most likely the case if it has at least one closed loop, or cycle, defined as a path from one node to itself from one of its outgoing arrows. Graphs with closed loops are called directed cyclic graphs in graph theory and causal loop diagrams in the system dynamics school of thought. The graph in figure 4 has 3 closed loops:

- 2-5-8-6-4-2 (from absorbed radiation to itself via air temperature, water vapor in air, cloud cover and short wave reflection).

- 2-5-7-11-3-12-2 (from absorbed radiation to itself via ocean temperature, etc.)

- 2-5-9-12-3-2 (via green plant photosynthesis).

The qualitative analysis of causal loops diagrams consists in decomposing it in its elementary closed loops and studying the equilibrium property of the dynamical relations resulting from the interplay of positive and negative feedbacks. Indeed, closed loops are the graphic equivalent of feedbacks mechanisms: positive if their overall effect is positive, negative one in other case. The sign of a closed loop and of its associated feedback mechanism depends on the number of positive and negative edges it is made off. If the number of negative influences is even, we are dealing with a positive feedback; if it is odd, the feedback is negative. Positive feedbacks are at the heart of amplifying mechanisms (more and more or less and less); stabilizing mechanisms involve negative feedbacks. However, likewise the ‘nth’ order indirect effects, there can exist ‘nth’ order feedbacks loops in causal loop diagrams. To discover them and explore their consequences for the stability of the system it is necessary to use more sophisticated techniques[26]. Unfortunately, these techniques are almost intractable with more than a few variables. When the model includes more than 5-6 variables it is probably better to use simulation as with Fuzzy Cognitive Maps.

Cognitive maps and causal loop diagrams are widely used in strategic management as a collaborative tool for extracting local knowledge from managers or as expert building tool in computer science. We don’t know of examples of using cognitive maps in environmental assessment. However, we know of one interesting application in participative environmental management. Özesmi[27] (1999) used them in its Ph.D dissertation on the sustainable development and participative management of the Kizilirmak Delta in Turkey to explore and model the perceptions and representations of the different stakeholders on the area. Practically, he built a total of 31 cognitive maps, of which 15 were drawn by villagers coming from 5 villages, 2 were drawn by vacation home owners, 7 were drawn by local and national NGO officials, 7 were from government officials. The cognitive maps were then transformed according to graph theory into adjacency matrices. The 31 maps were then additively superimposed forming what can be called a “social cognitive map”. Figure 5 shows a cognitive map drawn with one of the villagers.

[26] See Puccia, C.J. and R.Levins, 1985, *Qualitative Modeling of Complex Systems*, Harvard University Press, Cambridge, Mass. And London.

[27] Özesmi, U. 1999. *Conservation Strategies for Sustainable Resource use in the Kizilirmak Delta*, Turkey., University of Minnesota, Ph. D. Dissertation.

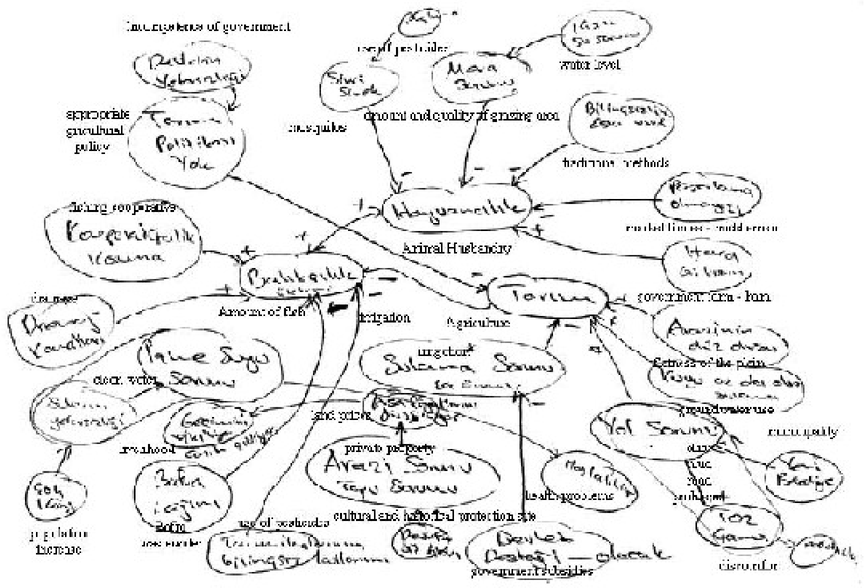


Figure 5. Cognitive map of the Kizilirmak Delta by a villager. Source: Özesmi, 1999.

2.2.1.4 Cognitive maps + numerical values + time = Fuzzy Cognitive Maps

Fuzzy cognitive maps (FCM) have been created by Kosko[28] by adding the following properties to cognitive maps:

- edges can take any real (constant) value in the [-1, +1] interval;
- nodes can take values in the set {-1, +1}or in the set {0,1};
- nodes are time-valued;
- The value of each node at any time is a function of the weighted sum of all its incoming edges, time the value of their outgoing node at previous time. In short:

$N_{it} = f(\Sigma\, w_{ji}N_{jt-1})$ where:

- N_{it} is the value of node ***i*** at time ***t***;
- w_{ji} is the weight of connection from node **j** to node **i**.
- N_{jt-1} is the value of node **j** at time t-1.
- f is a function (a logistic function usually), such that $-1 \geq N_{it} \leq +1$ or $0 \geq N_{it} \leq +1$.

Therefore, FCM are discrete dynamical systems. For instance, the cognitive map of global warming (figure 4) can easily be transformed in a FCM by giving values to the edges and assigning initial values to each node.

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[28] Kosko, B, 1986, Fuzzy cognitive maps, *International Journal of Man-Machine Studies* 1:65-75. See also Kosko, B., 1992, *Neural Networks and Fuzzy Systems. A Dynamical Systems Approach to Machine Intelligence*. Prentice Hall , Englewood Cliffs, New Jersey.

A FCM must be initialised with a vector of values, then its dynamical properties can be analysed by iterations until it ends with a fixed point attractor or a reach a limit cycle. Simulations can be conducted by changing one or several values of the vector of initial values. Thus, if one or several variables (nodes) represent policy's measures, it is possible to explore their likely impact on the dynamical behaviour of the system.

As illustration, let us mutate the cognitive maps of figure 4 in FCM. To do this, we give real values to edges in the range [-1,+1] and values to nodes in the set {-1,0,+1} giving them the following semantics:

- -1 = below normal
- 0 = normal
- +1 = above normal

The values given to edges are arbitrary except for the sign, which is the same that in figure 3. Figure 5 shows the FCM in initial stage, where all variables are at their normal position. Notice that we added a new variable: fossil fuel burning that acts on CO_2 in atmosphere.

The simulation consists in giving an impulse to this new variable and observe what is going on for the whole system. Table 6 shows how the values of state variables (nodes) evolve through time.

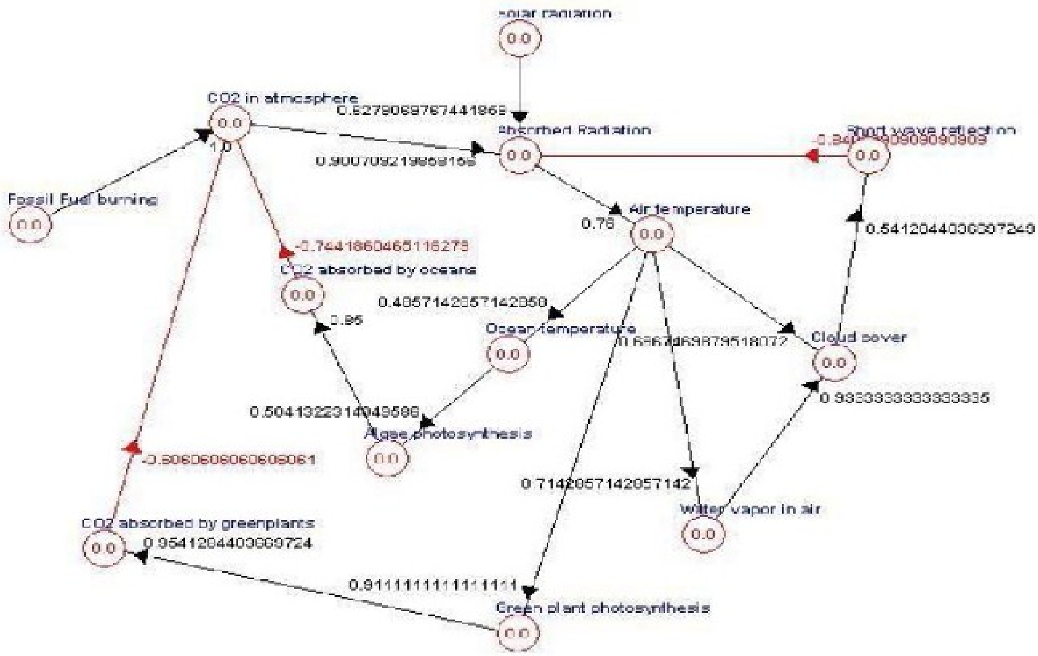


Figure 6. Fuzzy cognitive map of the greenhouse model.

TIME	Solar radiation	Aborbed radiation	CO2 in atmosphere	Short wave reflection	Air temperature	Cloud cover	Ocean temperature	Water vapor in air	Green plant photosynthesis	Algae photosynthesis	CO2 absorbed by oceans	C02 absorbed by green plants	Fossil fuel burning
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	1
2	0	0	1	0	0	0	0	0	0	0	0	0	1
3	0	1	1	0	0	0	0	0	0	0	0	0	1
4	0	1	1	0	1	0	0	0	0	0	0	0	1
5	0	1	1	1	1	1	0	1	1	0	0	0	1
6	0	1	1	1	1	1	0	1	1	0	0	1	1
7	0	0	0	1	1	1	0	1	1	0	0	1	1
8	0	-1	0	1	1	1	0	1	1	0	0	1	1
9	0	-1	0	1	-1	1	0	0	0	0	0	1	1
10	0	-1	0	1	-1	-1	0	-1	-1	0	0	0	1
11	0	-1	1	-1	-1	-1	0	-1	-1	0	0	-1	1
12	0	1	1	-1	-1	-1	0	-1	-1	0	0	-1	1
13	0	1	1	-1	1	-1	0	-1	-1	0	0	-1	1
14	0	1	1	-1	1	0	0	1	-1	0	0	-1	1
15	0	1	1	-1	1	0	0	1	-1	0	0	1	1
16	0	1	0	-1	1	0	0	1	-1	0	0	1	1
17	0	-1	0	1	1	0	0	1	-1	0	0	1	1
18	0	-1	0	1	-1	0	0	1	-1	0	0	1	1
19	0	-1	0	1	-1	1	0	-1	-1	0	0	1	1
20	0	-1	0	0	-1	-1	0	-1	-1	0	0	-1	1

Table 6. Results of simulation with the figure 5 FCM.

We see that the addition of CO_2 in atmosphere coming from burning more fossil fuels has the immediate effect of warming the atmosphere but also that it triggers a feedback mechanism that will eventually have the reverse effect. The feedback mechanism acts by increasing water vapour in air, green plant photosynthesis and *in fine* CO_2 absorbed by plants.

However, if we continue to burn too much fossil fuel, the whole system oscillates between periods of higher air temperature followed by periods of lower air temperature. As modelled here, the impact of ocean temperature, algae photosynthesis and CO_2 absorbed by oceans is nil. This is because we gave a too low value to the edge linking air temperature to ocean temperature. If we boost it slightly; it contributes to the homeostasis of the system by triggering the negative feedback.

Of course, this is a very crude model of the greenhouse effect and the values given to the relations between variables are totally fancy. But we can make our model more realistic, for example by introducing another (but positive) feedback mechanism missing in our first version: The effect on long wave absorption by water vapour is such a positive feedback, or the reduction in permafrost area that could let go huge amounts of methane. Figure 7 shows a FCM taking them into account.

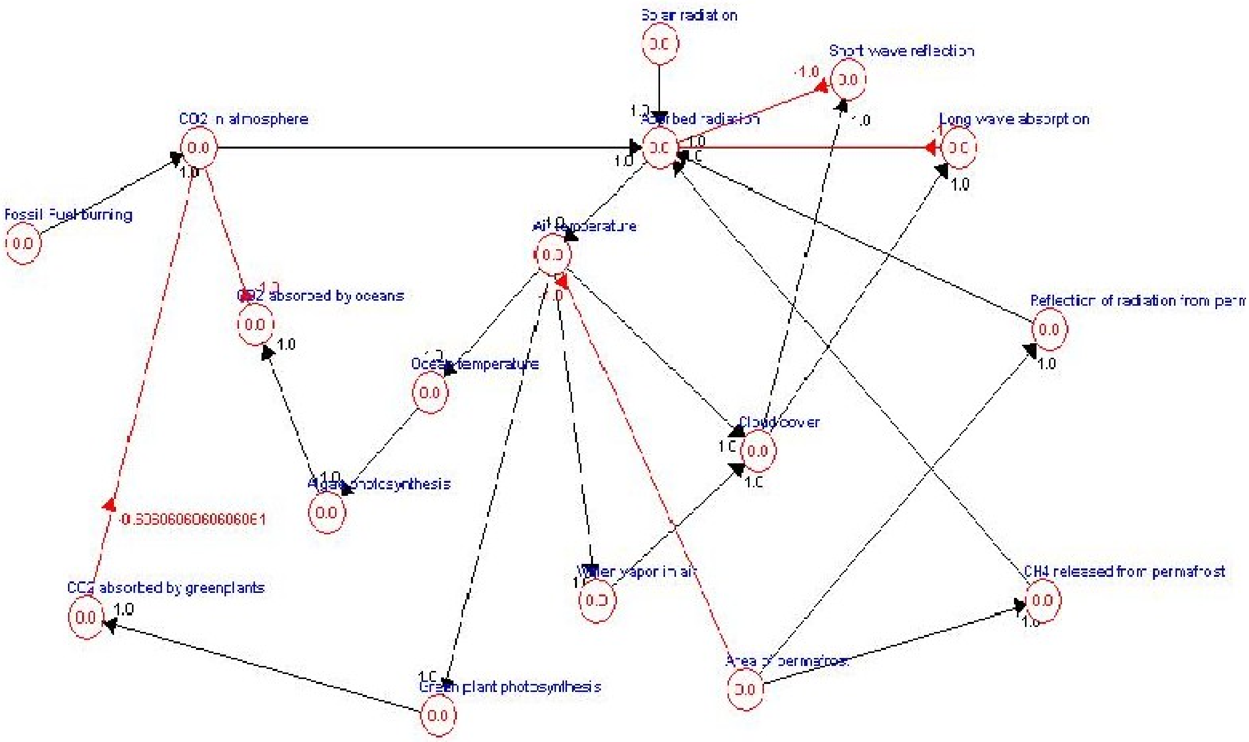


Figure 7. An augmented FCM of the greenhouse effect.

What is interesting in FCM from a cognitive integration point of view is that it is possible to superpose additively FCM from different stakeholders in order to compose something like a "social FCM". The final SFCM will include all the nodes present in the partial FCM while the values of the edges will be calculated as – possibly weighted –averages of values given in the partial FCM. Hence, FCM is a truly participative integration tool. Of course, it suffers from serious flaws that make them unsuitable for some kind of problems. Notably, it is impossible with "classical" FCM to model irreversible phenomena such as, for example, the depletion of a non-renewable stock, or, inversely, cumulative impacts. Only system dynamic models make this possible for the moment. However, nothing prevents us from endowing FCM with this additional possibility. It boils down to allow edges from one node to itself or, what is equivalent, to change the equation driving node evolution as follows:

$\mathbf{N_{it} = f(\Sigma\, w_{ji}N_{jt-1} + N_{i,t-1})}$ instead of the usual $\mathbf{N_{it} = f(\Sigma\, w_{ji}N_{jt-1})}$. However, it would also be necessary to get rid of the restrictions to the allowed nodes' values.

This would make FCM still closer to full-fledged (discrete) system dynamic models.

2.2.1.5 *Fuzzy Cognitive Maps (Directed cyclic graphs)+ stocks-flows = System Dynamics models*

Figure 8 shows a FCM of a simple population model taking into account some crowding effects on fertility and mortality. Crowding increase with population growth but contributes to regulating population by acting on mortality, which it increases, and fertility which it tampers. A FCM of such a system can only uncover its general dynamical behaviour. In order to predict the actual values of the different variables, it is necessary to give them real values and to allow for accumulation in stock variables.

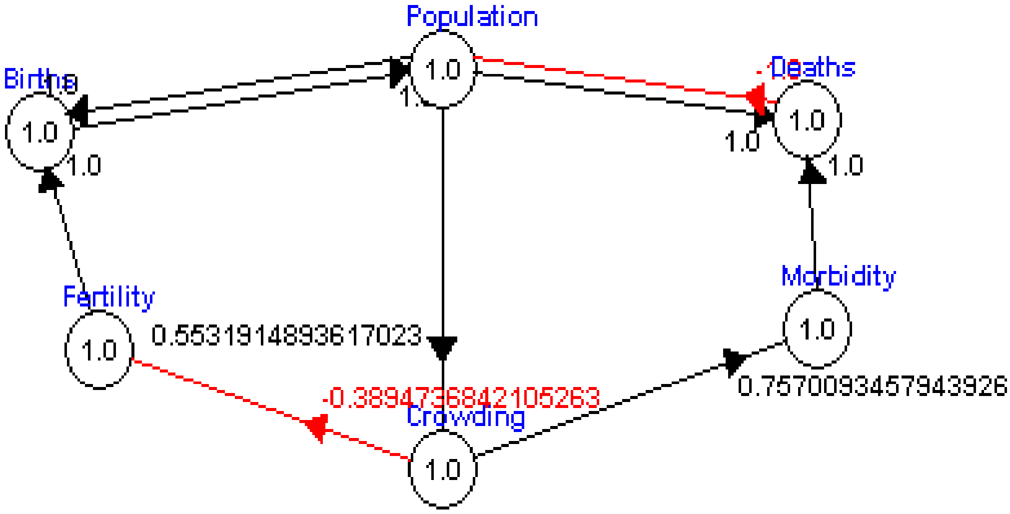


Figure 8. A FCM of a simple population system

This is exactly what system dynamics (SD) models do. Figure 9 shows the equivalent in SD of FCM in figure 8.

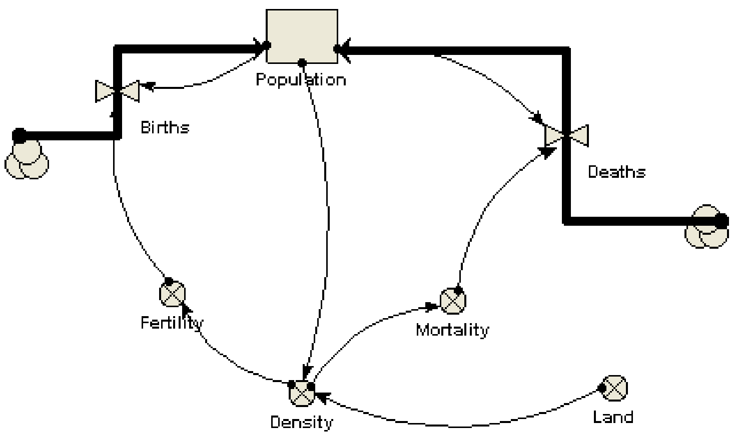


Figure 9. The population model in SD graphical mode

System dynamics (SD) models are fully-fledged representation of continuous dynamical systems allowing the modelling of all kind of behaviour, including accumulation or depletion. Contrary to FCM they allow nodes and edges taking real values in the interval - ∞ to + ∞. Basically, SD Models are graphical models (directed cyclical graphs) associated to the following semantics:

- nodes represent stock variables, fed by incoming edges and depleted by outgoing ones. They are called *levels* and are equivalent mathematically to integral equations. If a node has no parent (no incoming edge) it is called a source, if it has no child (outgoing edge), it is called a sink. Non-renewable resources are, for instance, easily modelled as sources.

- Edges correspond to derivative or differentials. They are called *flow* or *rate* variables because they act on levels, making them growing or decreasing. Actually, levels act on other levels by rates variables.

- Time is usually continuous and the model is numerically simulated using algorithms such as, for instance, Runge-Kutta algorithm.

The first real global integrated impact assessment models, the (in)famous "Limits to Growth" models to the Club of Rome by Meadows and alii, were also the first system dynamic models to reach a wide audience. System dynamic methodology has become a well-recognised tool in environmental modelling and management as well as in business but it still suffers from a bad reputation amongst economists. This is somewhat undeserved and has more to do with the way it has sometimes been used than with supposed inherent flaws. It is also that system dynamics models are, as their name makes clear, dynamical, yet economists are more used to static equilibrium or optimisation models.

2.2.1.6 Direct acyclic graph (DAG) + probabilities = Bayesian Network

Cognitive maps and fuzzy cognitive maps use some properties of graphical models to express the causal relations between variables. Indeed any cause-effect relation can be graphically depicted as a (directed) graph consisting in a set V of vertices (or nodes) representing the causes and the effects (variables, events, concepts…) and a set E of Edges (or links) connecting every pair of node for which a cause-effect relation holds. The fact that the relation is causal is implicit in the fact that the edges are oriented in the direction of the causal relation, i.e. from the cause to the effect. A causal diagram or graph is thus necessarily directed even if all directed graphs are not necessarily causal diagrams.

Figure 10 is an illustration of such a causal diagram. It describes the relationships between the season of the year (X_1), whether rain has fallen or not (X_2), whether the sprinkler is on or off (X_3), whether the pavement would get wet (X_4) and whether it would get slippery (X_5). Wetness causes the pavement to be slippery. Wetness itself is caused either by the rain or by the sprinkler being on, which depends on the season.

The graph is said to be acyclic because there is no path from one node to itself that follows the direction indicated by the edges (arrows) going out of it. This means, in the language of structural equation models (where they are called non-recursive) or of system theory that there is no feedback in the causal chain. Indeed, slippery doesn't cause wetness, or wetness rain, or rain falling being in whatever season. Of course, the real world is full of causal mechanisms with feedbacks, negative or positive so more often then not, causal diagrams will be cyclic. However, it is to be noted that any directed cyclic graph can be converted in a directed acyclic graph (DAG) just by duplicating and time-indexing some of its nodes. For instance, if node X is member of a path it can be duplicated in X_t and X_{t+1} , in to suppress the cycle it is included in.

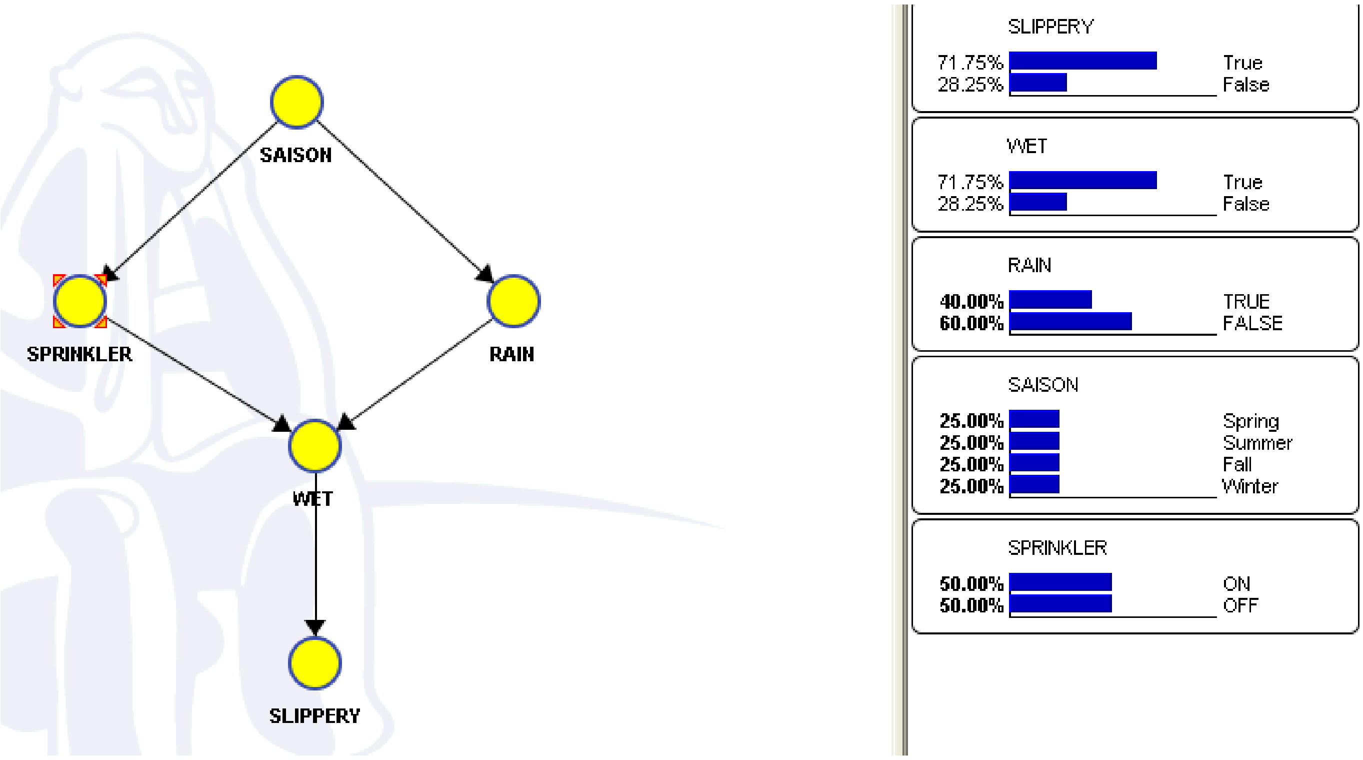


Figure 10. An example of Bayesian network

A DAG associated with a set of probability distributions is called a Bayesian network. In other words, Bayesian networks are directed acyclic graphs (DAGs) in which the nodes represent variables of interests and the links represent causal influences among the variables. The strength of the influence is represented by conditional probabilities that are attached to each cluster of parents-child nodes in the network.

The conditional probabilities corresponding to figure 10 are expressed in the following equations:

$$p(X_1,X_2,X_3,X_4,X_5)= p(X_5|X_4,X_3,X_2,X_1) = p(X_5|X_4)p(X_4|X_3,X_2)p(X_3|X_1)p(X_2|X_1)p(X_1) \qquad (1)$$

Compare equation (1) with equation (2) that is a strict application of the chain rule of probabilities for the computation of the joint probability distributions of the variables in the figure 1.

$$p(X_1,X_2,X_3,X_4,X_5)= p(X_5|X_4,X_3,X_2,X_1)p(X_4|X_3,X_2,X_1)p(X_3|X_2,X_1)p(X_2|X_1)P(X_1) \qquad (2)$$

(1) is much simpler than (2) because if takes into account the conditional independence relations expressed by the DAG of figure 10. Indeed, the figure 10 shows that different variables are not sensitive to all their predecessors in the graph but only to a subset of them. The subset of all the predecessors of one variable in a DAG on which this variable is sensitive is called its Markovian parents, or its parents for short.

Formally: Let $V = \{X_1,\ldots,X_N)$ be an ordered set of variables and let $P(v)$ be the joint probability distributions on these variables. A set of variables PA_j is said to Markovian parents of X_j if PA_j is a minimal set of predecessors of X_j that renders X_j independent of all its other predecessors.

In the example of figure 10, once we know that pavement is wet, we don't need any further information on the state of the sprinkler or the probability of rain, not speaking of the season in order to predict the slipperiness of the pavement. In the same way, once we know that the sprinkler is ON we are not interested anymore in the probability of rain in order to predict if the pavement will be wet or not. Fixing a variable in a Bayesian network to some of its possible value is called "conditioning on" it. For instance, fixing X4 = 'ON' or 'OFF' is equivalent to fixing [p(X_4='ON') = 1 and p(X_4='OFF') = 0] is said conditioning on X4. It is apparent from figure 1 that conditioning on X_4, X_5 is conditionally independent of all the other variables of the DAG, because they convey no more information on it.

The conditions of conditional independence and dependence in a Bayesian network are entrenched in the topology of its graph. They correspond to conditions of "D-separateness" which can appear in three topological patterns.

- The chain : "x -> m ->y " . x and y are conditionally independent, knowing m.
- The fork: " x <- m -> y. x and y are conditionally independent, knowing m
- The inverse fork : "x -> m <- y". x and y, while marginally independent, are conditionally dependent knowing m because once m is known, an information on x (y) lowers the probability of y (x).

In the chain and fork configuration, x and y are marginally dependent but become independent once we condition on m (i.e. once we know the value of m). The information on m "blocks" the information flow between x and y. Knowing m, the observation of x (y) is of no use in order to predict y (x). For example, in figure 10, once we know the season, X_2 and X_3 are independent, assuming that the sprinklers are set in advance, according to the season.

In the inverted fork case, when an effect can be the product of two separated causes it is the opposite. The two causes (x and y) are marginally independent but become conditionally dependent once we know m. Referring to figure 10, finding that the pavement is slippery or wet, makes X_2 and X_3 dependant since knowing one of them helps in predicting the other (refuting the falling of rain make sprinkler = off more likely).

Note that the all variables in figure 10 are discrete, as is usually the case in Bayesian networks. However, it could include also continuous variables defined by their distribution (Gaussian, most often) and their parameters (mean, variance). One speaks then of mixed Bayesian (or graphical) models.

Bayesian networks can be used for different purposes. They can help in explaining, predicting and intervening.

(a). *Prediction* consists in using elementary probabilities rules, mainly the following:

p(effect|cause) = p(effect & cause) / p (cause)

Therefore, once the cause is observed, it is possible to predict the probability of occurrence of the effect.

(b). *Explanation* is possible thanks to the Bayes theorem (which gives its name to the method), that states that:

p(cause|effect) = [p(effect|cause) * p(cause)] / p(effect)

In words, once an effect is observed, it is possible to go up to its most likely cause by using Bayes theorem in use, which gives us the probability of the cause knowing the effect.

(c). *What* about *intervention*? What is the difference, for example, between observing that the sprinkler is ON (refer to figure 1) and manipulating the sprinkler and turning it on? Or between predicting the probability that it rained after observing that the pavement is wet or after having made it wet? It is of course totally different. Though, Bayesian mathematical formalism doesn't make a difference between the two problems, it is expressed with the same formula: p(rain|wet). This is why Pearl suggested to create the new symbol 'do' and to introduce it in Bayesian network. If we follow him, we will be able to distinguish between p(rain|wet) which reads "probability of rain given that we **see** wet" and p(rain|do(wet)) which reads "probability of rain knowing that we **did make** it wet".

The difference between the two formulations corresponds to what Pearl calls a surgery on the DAG. The surgery of doing "sprinkler = ON" is visible in figure 11.

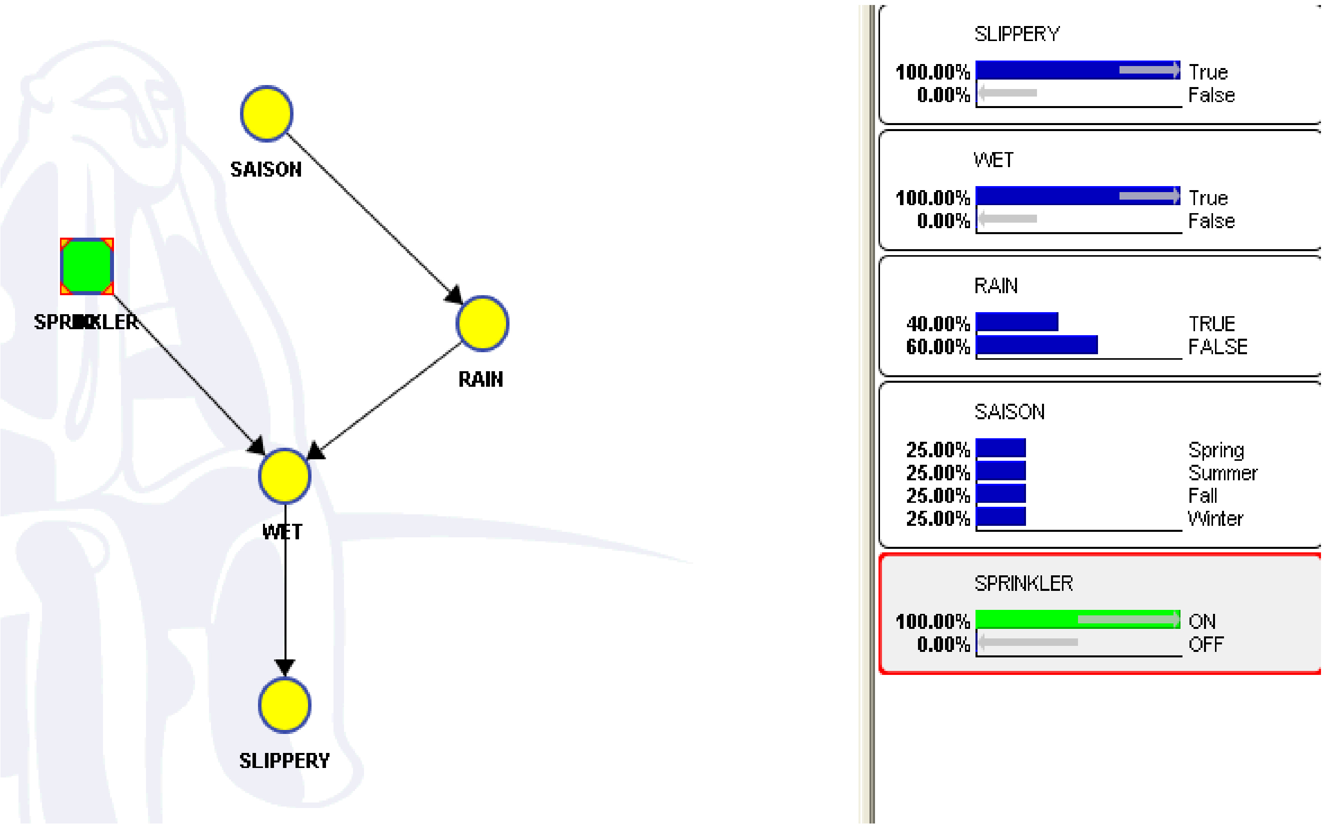


Figure 11. Bayesian network representation of the action "turning the sprinkler On".

The difference with figure 10 is in the removal of the arrow from X_1 to X_3. It represents the fact that, whatever relationship existed between seasons and sprinklers prior to action, that relationship is no longer in effect while we perform the action.

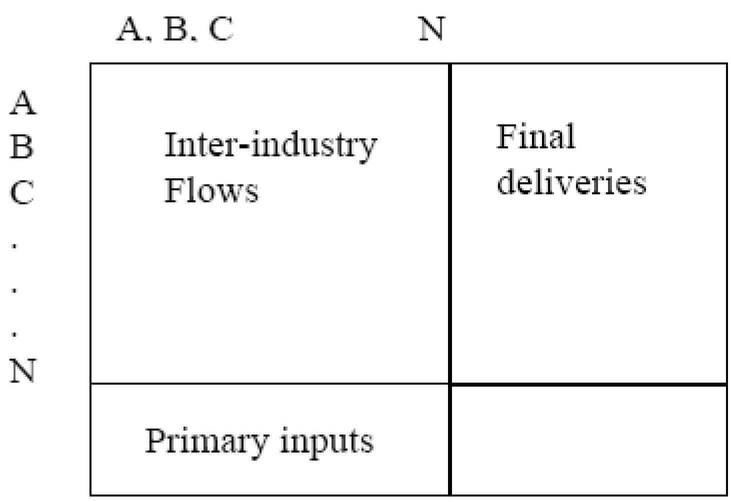
Thus, Bayesian networks allow an intuitive representation of policy intervention from outside on a pre-existent reality made of causal relations.

2.2.2 An accounting integration toolbox: SAM, NAMEA and structural economics

2.2.2.1 Foundations of the approach

The cornerstone of structural economics is the supply-uses table that links together the production of goods and services of all the industries by expressing each industrial final production as a combination of goods and services coming from itself and from the other industries of the considered economy. The structure of such tables is shown in table 7.

Table 7. A Schematic supply-uses table.



A,B, C ..N are the different industries taken *latu senso,* that is including services.

The table is summarizing a set of linear relations such as:

xA = **aA** + **bB** + **cC**……+**nN** + **Y**

Which express that in order to produce **x** units of **A** you need **a** units of **A**, **b** units of **B**, **c** units of **C** ….**n** units of **N**, **Y** being the final delivery to households and institutions. **A** could mean wood production, **B** buildings, furniture, etc. **A**,**B**, etc. can be expressed either in physical or in monetary units. This requires a workable classification of industries and data about their production and intermediary consumption patterns. For instance, Belgian input-output tables are build on the NACE classification, which is an European standard.

Primary inputs are necessary inputs that are not produced inside the considered economy but are coming from outside: other economies or nature.

Table 8. Schematic supply-uses table in physical units

		Extraction	Production	Households	TOTAL
Extraction (cubic meters)		25	20	55	100
Production (metric tons)		14	6	30	50
Households	Labour (hours)	70	140		210
	Capital (Tons)	10	40		50

If one divides each figure in the supply-uses table by its corresponding row total, one obtains a matrix of coefficients a_{ij} expressing the number of units of industry **i** needed to produce one unit of industry **j** product.

Table 9. Technical coefficients corresponding to table 8.

		Extraction	Production
Extraction		0,25	0,40
Production		0,14	0,12
Households	Labour	0,70	2,80
	Capital	0,10	0,80

The technical coefficients can be normalized (divided by their column total) giving the well-known input-output table, which describes the production structure of the economy.

Table 10. Input-output table corresponding to supply-uses table 8

.		Extraction	Production
Extraction		0,21	0,01
Production		0,12	0,29
Households	Labor	0,59	0,68
	Capital	0,08	0,02

Here, the production sector appears to be more labor intensive but less capital intensive than the extractive sector. Now, if the cubic meter's price is 2 € and the metric ton's price 5 €, if the wage rate is 1 € /hour and interests on capital 20%, we have the monetary equivalent of table 8 in table 11.

Table 11. Schematic input-output table in €.

		Extraction	Production	Households	TOTAL
Extraction		50	40	110	200
Production		70	30	150	250
Households	Labor	70	140		210
	Capital	10	40		50
TOTAL		200	250	260	710

Usually, the A matrix of technical coefficients is calculated from input-output tables in money unit, as in table 12.

Table 12. Technical coefficients from table 8.

		Extraction	**Production**	**Households**
Extraction		**0.25**	**0.16**	**0,423**
Production		**0.35**	**0.12**	**0,577**
Households	**Labor**	**0.35**	**0.7**	**0**
	Capital	**0.05**	**0.16**	**0**

One sees that, when technical coefficients are calculated directly from a supply-uses table in money units, they are all necessarily less than or equal to 1, and row sums are equal to equivalent columns sums.

Let us call **A** the matrix of technical coefficients, **y** the vector of final demand, **x** the total output vector. Then the following relations holds:

$$\mathbf{y} = \mathbf{x} - \mathbf{Ax}$$

This expresses the fact that final deliveries are the difference between total production and intermediary consumption, that is the part of production consumed to produce other final goods and services.

It is always liable to multiply a matrix by the identity matrix **I** without changing its value, so:

$$\mathbf{y} = \mathbf{Ix} - \mathbf{Ax}$$

Therefore:

$$\mathbf{y} = \mathbf{x}(\mathbf{I} - \mathbf{A})$$

$$\Rightarrow \mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$$

The above expression can only be solved if **x** or **y** are exogenously given.

$\mathbf{(I - A)}^{-1}$ is called the Leontief inverse. It allows computing the production required (**x**) for any final income **y,** taking into account the intermediary consumptions. Indeed, the Leontief inverse gives the 'direct' requirements of input for each unit of output as the table of technical coefficients plus all the indirect requirements.

Suppose we want to consume (final demand) 1 unit more of each production, if they were no intermediary consumption, it would suffice to produce the vector **I** of these additional units. However, because of the intermediary consumption (productive consumption) we need also to produce **A**, and then the total required production is **I** +**A .** But, **A** itself needs **A** more to be produced, etc. All in all we need a total production of:

$$\mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \ldots. + \mathbf{A}^n$$

All the coefficients in **A** being < 1, $\mathbf{A}^n$ converges to 0 as n goes to infinity. But, $\mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \ldots.+\mathbf{A}^n$ is the development of $\mathbf{I} / (\mathbf{I} - \mathbf{A})$ or $\mathbf{(I - A)}^{-1}$.

There is an equivalent of the Leontief matrix if the transactions are expressed in money. Suppose **v** is the vector of added values, **p** the vector of prices, then we have

$$\mathbf{p} - \mathbf{A'p} = \mathbf{v} \Rightarrow \mathbf{p} = (\mathbf{I} - \mathbf{A'})^{-1}\,\mathbf{v}.$$

It states that the price of a unit of output (**p**) is equal to the cost (quantity times prices) of input (**A'p**) plus value-added (**v**).

2.2.2.2 Introducing the environment

In the example above, although an extracting activity was recorded, the natural resource itself was absent as well as the corresponding rent. In the following example[29] both activities and resources are taken into account. Suppose a hypothetical economy producing wheat, coal, iron pellets, machinery and electricity using labor, capital, land, raw coal and iron ore as factors of production. Outputs of the first three sectors are measured in tons; machinery in numbers of units and electricity in kWh. Land is measured in hectares, raw coal in tons, iron ore in tons of metal content, labor in person-years and capital in $.

Table 13 shows the technical coefficients extracted from the inter-industry supply-uses tables and the coefficients calculated from the activities-factors supply-uses table. The former is the classical **A** matrix. Lets us call the latter the **F** matrix.

Table 13. **A** and **F** Matrices for an hypothetical economy

A Matrix	Wheat	Coal mining	Iron mining	Machinery	Electricity
Wheat	0.020	0.000	0.000	0.000	0.000

29 From Duchin, F., 2004, "Input-Output economies and material flows", Rensselaer Working Paper in Economy, N° 0424, December 2004..

Coal mining	0.000	0.023	0.214	0.259	0.833
Iron mining	0.000	0.000	0.286	0.556	0.139
Machinery	0.020	0.068	0.143	0.111	0.278
Electricity	0.049	0.045	0.179	0.370	0.056
Table 13 continued					
F Matrix	Wheat	Coal mining	Iron mining	Machinery	Electricity
Land	0.245	0.045	0.107	0.000	0.000
Raw coal	0.000	1.250	0.000	0.000	0.000
Iron ore	0.000	0.000	1.071	0.000	0.000
Labor	0.196	0.182	0.286	0.444	0.056
Capital	0.980	2.727	5.714	11.111	16.667

Table 14. Values for exogenous vectors **y** and **π** and calculated values for endogenous vectors

	Exogenous	Endogenous		
	y	**x**	**v**	**p**
Wheat	100	102	6.23	9.28
Coal mining	0	44	9.66	15.23
Iron mining	0	28	8.32	35.99
Machinery	5	27	7.56	51.29
Electricity	12	36	4.00	38.06
	π	**f**		
Land	15	30		
Coal	5	55		
Iron	2	30		
Labor	12	50		
Capital	0.2	1280		

We have two production equations here. The first is the already encountered one:

$$(\mathbf{I} - \mathbf{A})\mathbf{x} = \mathbf{y}$$

The second is **Fx** = **f**, with **f** being the k vector of total factor use in physical unit. Let **p** be the vector of prices and **v** the value-added as above. Let **π** be the k-vector of factors prices. Then:

$$(\mathbf{I} - \mathbf{A}')\mathbf{p} = \mathbf{F}'\boldsymbol{\pi}$$

$$\mathbf{py} = \pi\mathbf{Fx}.$$

Table 14 shows values for exogenous variables **y** and **π** and solutions values for endogenous variables **x**, **p**, **f** and **v**, where factor use is calculated as $\mathbf{f} = \mathbf{Fx}$ and value-added as payments to all factors per unit of output or, $\mathbf{v} = \mathbf{F}'\pi$.

The rent for land is observed as 15 $ /ha and the royalties for coal are 5$/tons. Wages are 12$/person-year. To quantify the dependence of all sectors on the individual resources inputs, we calculate the k * n matrix $\mathbf{F}(\mathbf{I} - \mathbf{A})^{-1}$ where each entry measures the amount of one factor required directly and indirectly to deliver a unit of final deliveries of product. This is shown in table 15.

Table 15. Factor Requirements to satisfy final deliveries ($\mathbf{F}(\mathbf{I} - \mathbf{A})^{-1}$)

	Wheat	Coal	Iron	Machinery	Electricity
Land	0.265	0.074	0.272	0.268	0.184
Raw coal	0.160	1.548	1.500	1.829	2.273
Iron ore	0.087	0.175	2.171	2.336	1.011
Labor	0.287	0.356	1.117	1.739	1.049
Capital	4.438	8.821	33.372	55.355	46.619

It shows that even if each sector doesn't require directly every factor, all of them use every factor indirectly. For example, delivering 100 tons of wheat to final consumer requires 27 ha of land, 16 tons of raw coal, 9 tons of Iron ore, etc.

The same logic can be used to calculate prices paid, directly and indirectly to each factor of production. It is given by the matrix $\pi'\mathbf{F}(\mathbf{I} - \mathbf{A})^{-1}$, π' being the price-vector of factors.

2.2.2.3 Introducing the social pillar: the Social Accounting Matrix

Another extension of the input-output matrix consists in adding institutions, notably households but also government, forming what R.Stone called the "Social Accounting Matrix" (SAM), "*a comprehensive, flexible, and disaggregated framework which elaborates and articulates the generation of income by activities of production and the distribution and redistribution of income between social and institutional groups. A principal objective of compiling a SAM is, therefore, to reflect various interdependencies in the socioeconomic system as a whole by recording, as comprehensively as is practicable, the actual and imputed transactions and transfers between various agents in the system. The key distinguishing features of the SAM relative to alternative accounting systems are, first, the system is represented by a set of single-entry accounts; secondly, it places relatively more importance on the factoral, household and institutional dimensions; and thirdly, the framework is complete and comprehensive*."(Round, 2003, p.2)

A SAM is a square matrix where rows and columns refer to activities (the industries of the basic I-O model), factors (the value-added is disaggregated as factors payments) and institutions (which own factors and pay for final deliveries). Table 16 shows a condensed macro-SAM.

Table 16. *A simplified macro-SAM.*

Table 1: Macro SAM

	Activities	Commodity	Factors	Hshld	Govt	S-I	World
Activities		D					E
Commodity				C	G	I	
Factors	X						
Household			Y				
Government	T^X			T^H			
S-I				S^H	S^G		S^F
World		M					

Definitions:

D: production sold domestically	C: consumption
E: exports	G: government demand
X: production (GDP at factor cost)	I: investment demand
T^X: indirect taxes	S^H: household savings
T^H: direct taxes on households	S^G: government savings
M: imports	S^F: foreign savings
Y: factor payments to households	S-I: savings-investment account

One can verify that the fundamental macroeconomic identities are preserved:

- GDP = X + T^X = D + E
- C + G + I = D + M (demand)
- GDP + (M – E) = C + G + I
- Y = X = GDP at factor costs

The SAM brings about three benefits

- its construction allows the collection and integration of information usually lacking in national accounts but very useful in order to characterize an economy;
- it displays this information in a illuminating way by emphasizing the structural interdependence of factors, activities and institutions at the macro and meso levels. Indeed, the SAM gives the possibility to disaggregate activities, factors and or institutions and moving from a macro to a meso perspective. For example, in the Indonesian SAM used by Duchin[30] (1998), households are disaggregated in the following classes: landless agricultural, small farmers, medium farmers, bigger farmers, rural non-farm low-status, rural outside labor force, rural high-status, urban low-status, urban outside labor force, urban high status. It can even be used at a micro-level, for example at village level in LDC[31].

30 Duchin, F, 1998, *Structural Economics. Measuring Change in Technology, Lifestyles, and the Environmen*t. Washington, D.C. : Island Press.

31 Taylor, J.E and Adelman (1996). *Village Economies: The Design, Estimation and Use of Villagewide Economic Models*. Cambridge: Cambridge Press.

- It allows multiplier analysis akin to the classical Leontief analysis of input-output table with the so-called “generalized Leontief matrix”. Multiplier analysis estimates the effects of one-time increases in exogenous variables on endogenous variables in the accounting framework and it is used for short-term policy analysis. Such an analysis is very useful in estimating the effects of exogenous variables, such as increases in exports, on outputs, employment and incomes, with each of these being disaggregated in relation to the classification system embodied in the social accounts. The richness of SAM multipliers comes from their tracing out chains of linkages from changes in demand to changes in production, factor incomes, households incomes, and final demands. However, multiplier analysis and the very computation of the generalized Leontief inverse call for the partitioning of the SAM in endogenous and exogenous transactions. In table 17 below, only A, F, C, W and T are endogenous, forming a sub-matrix **M**. **(I – M)** $^{-1}$ is the so-called “Generalised Leontief Inverse”.

Table 17. A partitioned simplified SAM with endogenous and exogenous accounts.

		EXPENDITURES				
RECEIPTS		***1 Production Activities***	***2 Factors of Production***	***3 Institutions***	***4 Other expenditures***	**TOTAL**
1.	***Production Activities***	**A**		**C**	**X**	**X**
2.	***Factors of production***	**F**			**X**	**X**
3	***Institutions***		**W**	**T**	**X**	**X**
4	***Other***	**X**	**X**	**X**	**X**	**X**
	TOTAL	**X**	**X**	**X**	**X**	**X**

Table 18 shows the matrix of coefficients (M) corresponding to a simplified SAM matrix for Indonesia(Duchin, 1998). It has to be read as following, for example: a 1.000.000 rupiah of output in agriculture needs 266.000 rupiah of agricultural inputs (seeds, fodder, etc.), 196.000 rupiah of manufactured goods, 204.000 rupiah of agricultural labour, etc. Table 19 shows the Leontief Generalised Inverse or multipliers matrix corresponding to the SAM coefficients matrix in table 11. It takes into account all direct and indirect effects

Table 18. Coefficient matrix for SAM for Indonesia 1980 (rupiahs of input per rupiah of output)

	1	2	3	4	5	6	7	8
1. Agriculture	**0.266**	**0.037**	**0.00**	**0.00**	**0.00**	**0.00**	**0.584**	**0.183**
2. Manufacturing & services	**0.196**	**0.237**	**0.00**	**0.00**	**0.00**	**0.00**	**0.243**	**0.206**
3. Agricultural labor	**0.204**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
4. Nonagricultural	**0.022**	**0.219**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

labor								
5. Agricultural capital	0.279	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6. Nonagricultural capital	0.00	0.394	0.00	0.00	0.00	0.00	0.00	0.00
7. Rural households	0.00	0.00	0.943	0.094	0.835	0.00	0.006	0.002
8. Urban households	0.00	0.00	0.057	0.906	0.00	0.942	0.007	0.049

One sees that in order to satisfy a 1.000.000 rupiahs additional final consumption of agricultural goods, one needs to produce a 2.51millions output of agricultural sector, 1.22 millions of manufactured output, etc.

Table 19. Multipliers for the SAM coefficients matrix of Indonesia, 1980 (Duchin, 1998)

	1	2	3	4	5	6	7	8
1. Agriculture	2.51	0.63	1.57	0.72	1.36	0.59	1.63	0.62
2. Manufacturing & services	1.22	1.88	1.15	0.69	0.99	0.61	1.18	0.64
3. Agricultural labor	0.51	0.13	1.32	0.15	0.28	0.12	0.33	0.13
4. Nonagricultural labor	0.32	0.43	0.29	1.17	0.25	0.15	0.29	0.16
5. Agricultural capital	0.70	0.18	0.44	0.20	1.38	0.16	0.46	0.17
6. Nonagricultural capital	0.48	0.74	0.45	0.27	0.39	1.24	0.47	0.25
7. Rural households	1.11	0.31	1.65	0.42	1.45	0.27	1.73	0.28
8. Urban households	0.82	1.15	0.81	1.40	0.65	1.38	0.77	1.46

2.2.2.4 Miscellaneous

- The SAM-NAMEA accounting framework can be used for modeling either in a neo-classical economics (with a CGE model) or in a “structural economics” way. The neo-classical economist approach is a static, comparative equilibrium one. The structural economics approach builds scenarios of significant changes in production technologies or households lifestyles and evaluate its effects on incomes, activities, factors uses, environment.

- The SAM-NAMEA framework can mix different measurements units: money, physical units and even time. Anyhow, the coefficients and the multipliers are dimensionless.

- It can be seen as an expansion of the Ehrlich accounting expression I = P*A*T which means that the impact on the environment of the consumption of any good is a function of the number of consumers of the good (P, for population), their level of consumption (A, for affluence), that is the number of units consumed by consumer, and the unitary environmental impact of the good. In the SAM scheme, the P factor is expressed as the number of (different kinds of) households, the A factor as their consumption habits or lifestyles (C matrix in table 10) and the T factor is the technologies embedded in the input-output matrix (matrix A in table 10) with respect to environment.

- Belgium already has only an embryo of NAMEA accounts and doesn't seem to be on the way to any social accounting matrix. In contrast, Statistics Netherlands already have an overall integrated environmental, social and economical accounting scheme called SESAME.

2.2.3 Conclusions and synthesis on cognitive integration tools

- Causal tools may be expressed either in matrix or in graphical form. The latter is more convenient for collaborative (participative) modelling, the former is best suited to mathematical manipulations. However, it is always possible to switch between the two modes of presentation.

- Though the impact assessment literature seems unaware of it, there is a whole continuum between purely qualitative causal framework (such as the DPSIR) and tools (such as checklist or cross-impact matrices) and fully quantitative models such as systems dynamics models. In between, one find semi-quantitative tools such as FCM (Fuzzy cognitive maps), or Bayesian networks[32]. It is therefore possible to enrich progressively the assessment as needed, beginning with a cognitive map, then quantifying it a bit as FCM, finishing if necessary and feasible with a full-fledged system dynamic model or, if risk is at stake, with a Bayesian network (or an influence diagram).

- In any case, it is helpful to start with a graphical model of the relations between the relevant variables (policy variables, identified impacts, intermediary variables). If the problem is mainly a dynamical one, the graph will contain cycles, and feedbacks will have to be considered. If not, it will boils down to an event tree likely to mutate to a Bayesian network if endowed with probabilities.

- Accounting integration is much more demanding in terms of existing database. It supposes the existence of highly disaggregated social accounting matrices, input-output tables and environmental accounts.

- Cognitive integration can be *ex post* or *ab initio*. If *ex post*, it can only be done by coupling pre-existing disciplinary causal models. The different causal integration tools discussed here can be used either *ex post* or *ab initio*. It is much less the case for the accounting approach. Integration of economical, environmental and social variables in SAM-NAMEA frameworks is mainly an *ab initio* process, because they must have been identified from the beginning in the categories of the accounted for activities, factors and institutions.

- The causal and accounting integration pattern differs also from a sustainable development point of view. For example, the accounting scheme is better suited to analysis of impacts on production and consumption patterns. On the other hand, a non-linear dynamical causal model is the only way to explore far from equilibrium behaviours. Likewise, the probabilistic approach of Bayesian networks is especially fitted to the evaluation of risks such as in health impact assessment.

Table 20 gives an overview of the strength, weaknesses and main characteristics of the two kind of integration patterns with respect to some requirements of sustainable development assessment.

Table 20. Overview of strengths and weaknesses of the main cognitive integration tools.

INTEGRATION OF	CI-Matrix/CM/FCM-/SD	Bayesian networks-	Accounting

[32] I don't mention here qualitative physics nor neural networks, the former because I don't believe in its potential in assessment (although I believe in its pedagogic virtues), the latter because of their "black box" character.

		influence diagrams	
Environmental, economical, social	Yes (*ex post* or *ab initio* coupling)	Yes (good in *ex post* coupling and reduced forms)	Yes but only *ab initio*
Different spatial scales	Difficult	Possible	No but possibly multi-regional, imports-exports
Different time scales	Yes but mostly long term	?	No (mostly short term)
Different kinds of knowledge (participation)	Yes for FCM, Difficult for SD	Yes (mixing objective and subjective probabilities)	No (dominance of the economical language)
Uncertainties, risks	Only by sensibility analysis	Yes	No
Sustainable.development paradigm	DPSIR --Resiliency Productive assets (long term)	DPSIR Procedural interpretation (precautionary principle)	Ehrlich equation Triple Bottom Line Productive assets (short term)
Sustainable development concerns and impacts	Environmental problems	Risks and uncertainties (health)	Production and consumption patterns
Strengths	Dynamical, non-linearities	Risk assessment	Coherence Social acceptability Objectivity Distributional concerns Close to life-cycle analysis, material flows
Weakness	Calibration highly demanding in data (less for FCM) and skills	Elicitation of Probabilities Subjectivity	Static framework Huge data requirements (national accounting system)

(to be continued…