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Technical Report on Environmental Sciences

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François Diaz-Maurin[1]

Affiliations:
[1]Institut de Ciència i Tecnologia Ambientals (ICTA), Universitat Autònoma de Barcelona (UAB), Facultat de Ciències, Campus de la UAB, 08193 Bellaterra (Cerdanyola del Vallès), Spain

Contact: François Diaz-Maurin <Francois.Diaz@uab.cat>

Date: *17-09-2012*

Refer to as:

Author: **F. Diaz-Maurin**
Year: **2012**
Title: **Assessing the Viability of Power-Supply Systems: A Tentative Protocol**

Reports on Environmental Sciences
http://www.recercat.net/handle/2072/16100

Institut de Ciència i Tecnologia Ambientals (ICTA)
Edifici Cn, Campus UAB
08193 Cerdanyola del Vallès, Spain
Tel: (+34) 935812974
http://icta.uab.cat
icta@uab.cat

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François Diaz-Maurin
Researcher and Ph.D. Candidate, Institut de Ciència i Tecnologia Ambientals (ICTA), Universitat Autònoma de Barcelona (UAB), 08193 Bellaterra, Spain

ABSTRACT

This Technical Report presents a tentative protocol used to assess the viability of power-supply systems. The viability of power-supply systems can be assessed by looking at the production factors (e.g. paid labor, power capacity, fossil-fuels) – needed for the system to operate and maintain itself – in relation to the internal constraints set by the energetic metabolism of societies. In fact, by using this protocol it becomes possible to link assessments of technical coefficients performed at the level of the power-supply systems with assessments of benchmark values performed at the societal level throughout the relevant different sectors. In particular, the example provided here in the case of France for the year 2009 makes it possible to see that in fact nuclear energy is not viable in terms of labor requirements (both direct and indirect inputs) as well as in terms of requirements of power capacity, especially when including reprocessing operations.

Keywords: Integrated Assessment, Biophysical Economics, Sustainability, Power-Supply Systems, Nuclear Energy, Fossil Energy.

Contents

List of Abbreviations

AG	agriculture sector
BM	building and manufacturing sector
CEA	French Atomic Energy Commission (*Commissariat à l'Energie Atomique*)
CCS	carbon capture and storage
EC	energy carriers
EM	energy and mining sector
HH	household sector
IGCC	integrated gasification combined cycle
ILO	International Labour Organization
INSEE	French National Institute for Statistics and Economic Studies (*Institut National de la Statistique et des Études Économiques*)
ISIC	International Standard Industrial Classification
LWR	light water reactor
NACE	Statistical Classification of Economic Activities in the European Community
NAF	French Statistical Classification of Economic Activities (*Nomenclature d'activités française*)
OECD	Organisation for Economic Co-operation and Development
PES	primary energy sources
PS	productive sector
PW	paid work sector
SA	societal average
TOE	ton of oil equivalent

Units

h	hour
J	joule
W or We	watt electric
Wh	watt-hour electric

SI unit prefixes

k	kilo (–10^3)
M	mega (–10^6)
G	giga (–10^9)
T	tera (–10^{12})
P	peta (–10^{15})

1. Introduction

This Technical Report presents a tentative protocol used to assess the viability of power-supply systems. The viability of power-supply systems can be assessed by looking at the production factors (e.g. paid labor, power capacity, fossil-fuels) – needed for the system to operate and maintain itself – in relation to the internal constraints set by the energetic metabolism of societies. That is, this protocol intends to map the characterization of the performance of power-supply systems (assessment of the technical coefficients and production factors, see Diaz-Maurin and Giampietro *forthcoming*) onto the characterization of the energetic metabolism of societies (characterization of how exosomatic energy is used within the different compartments of society, see Giampietro et al. 2012, Sorman 2011). I present here the main aspects of such a protocol – called the "viability protocol" throughout this report – using the example of the viability of the nuclear energy and fossil energy power-supply systems in the context of France in the year 2009.

2. Viability of Power-Supply Systems

In the discussions over sustainability, it is not always clear what *viability* means. Yet, it is possible to provide here a tentative definition of what viability is referring to when considering the bio-economic dimension of sustainability.

According to the Merriam-Webster dictionary[1], something is said *viable* when it is:
"*(1): capable of living;* especially *: having attained such form and development as to be normally capable of surviving outside the mother's womb <a* viable *fetus>; (2): capable of growing or developing* <viable *seeds*> <viable *eggs>; (3) (a): capable of working, functioning, or developing adequately*<viable *alternatives>, (b): capable of existence and development as an independent unit <the colony is now a* viable *state> (c) (1): having a reasonable chance of succeeding <a* viable *candidate>, (2): financially sustainable <a* viable *enterprise>*"

Following the definition found in the Merriam-Webster dictionary, the term "viable" is very close to the idea consistent with "internal constraints" (i.e. economically viable, capable of growing in biophysical terms, working functioning, having chance of succeeding in a competition). That is, the viability of a socio-economic system refers to its internal ability to establish a metabolic pattern interacting with its context both in biophysical and economic terms in a way that match internal and external constraints.

When looking at the viability of a power-supply system, it refers to the ability of the system to stabilize the metabolic pattern in relation to internal constraints (i.e. in terms production factors, such as power capacity or human activity) and economic activity (in fact a lot of modern societies are stabilizing their metabolic pattern because of trade that are measured through imports of goods and materials). These constraints are determined by the characteristics of the parts (e.g. unit operations of the system) operating within the black-box determining the overall characteristics of the capability of processing flows within the black-box (the overall power-supply system). Internal constraints are at play when external boundary conditions make it possible a further expansion, but the system cannot do it. For more information on the distinction between internal and external constraints in relation to power-supply systems, refer to Diaz-Maurin and Giampietro *forthcoming*.

The existence of the expected performance of society translates into a series of forced

1 http://www.merriam-webster.com/dictionary/viability (accessed 14 September 2012)

range of values of the variables (called "benchmarks") within the multi-level matrix of MuSIASEM (Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism, see Giampietro et al. 2012). Then, it becomes possible to assess the viability of the metabolic pattern in relation to the internal capability of the system (the technical coefficients of the activities carried out in the PS sector (level n-2) and the subsectors EM, AG, BM (level n-3). When dealing with power-supply systems, assessing the viability of the metabolic pattern means checking the compatibility of the performance of those power-supply systems (level n-5) with the benchmarks set by the electricity production sub-sector EM_{ELEC} (level n-4). The viability of power-supply systems can also be looked in relation to the BM sector – for the making and maintenance of fund elements (i.e. facilities needed for the processes to operate) – as well as the SG sector – for the electricity distribution, regulations, insurance and lobby activities that can be in some cases specific to every power-supply systems.

3. Applying the Dual System of Accounting of Energy Flows

This viability protocol builds upon previous work from Sorman and Giampietro who developed a protocol of energy accounting making it possible to trace energy throughput through the Primary Energy Sources (PES) – Energy Carriers (EC) – End Uses (EU) scheme (Sorman 2011, Giampietro and Sorman 2012). The choice of using those semantic categories (PES, EC and EU) reflects the various transformations on energy flows making up the societal throughput – i.e. exosomatic energy. In doing so, the protocol of energy accounting uses a multi-scale approach (based on the use of the MuSIASEM grammar, see Giampietro et al. 2012) that breaks down the aggregate consumption of energy assessed at the societal level of the whole economy into a series of assessments of expected consumption levels referring to lower compartments of society which are essential for the expression of the relative societal functions. Adopting this approach of energy accounting, it becomes possible to establish a series of expected benchmark values for the expected level of consumption within each of the compartments composing the metabolic representation of societies: energy and mining (EM), agriculture (AG), building and manufacturing (BM), service and government (SG), household (HH).

When tracking energy flows through the various compartments that build-up the society, it is essential to make a distinction between quantities of energy referring to Primary Energy Sources (measured in GJ-PES – also called Gross Energy Requirement – referring to the heat equivalent of a given amount of biophysical units such as TOE) and to Energy Carriers (measured in GJ-EC referring to the energy forms found when looking at technical coefficients experienced in final energy consumption). This set of energy transformations correspond to a series of two conversion processes taking place in cascade in society. For more information on the theoretical and practical aspects involved in the protocol of energy accounting followed in this TR, refer to Sorman 2011, Giampietro and Sorman 2012 and Giampietro et al. 2012.

3.1 The PES-EC transformation

The transformation of Primary Energy Sources (PES) into a given supply of Energy Carriers (EC) follows the logic proposed by Sorman (2011). Table 1 shows how the different PES categories (measured in Gross Energy Requirements or Heat equivalent formalized as MJ-PES) are used for making the three forms of EC – Fuel, Electricity and Heat.

PES Category	PES (using Eurostat nomenclature)	GER (Heat eq. in PJ)	Table	Indicators	EC Prod.
Petroleum products	Crude Oil [3105]	3,086	[nrg_102a]	[B_101000]	Fuel
	Feedstocks and other hydroca	295	[nrg_102a]	[B_101000]	Fuel
	TOTAL	3,381			
Petroleum products	Gas/Diesel oil [3260]	4	[nrg_102a]	[B_101001]	Elec
	Residual Fuel Oil [3270A]	43	[nrg_102a]	[B_101001]	Elec
Solid Fuels	Hard Coal and Patent Fuels [2	211	[nrg_101a]	[B_101001]	Elec
	Lignite and Deriv. [2200]	0	[nrg_101a]	[B_101001]	Elec
Gas	Derived Gas [4200]	23	[nrg_103a]	[B_101001]	Elec
	Natural Gas [4100]	239	[nrg_103a]	[B_101001]	Elec
Nuclear	Nuclear Power [16_107030]	3,877	[nrg_105a]	[16_107030, 16_107032] – Partial Subs	Elec
Renewables	Hydro Power [16_107034]	588	[nrg_105a]	[16_107034, 16_107035] – Partial Subs	Elec
	Wind Energy [5520]	28	[nrg_1072a]	[B_100100]	Elec
	Photovoltaic Power [5534]	0.62	[nrg_1072a]	[B_100100]	Elec
	Biomass & Wastes [5540]	60	[nrg_1071a]	[B_101001]	Elec
	TOTAL	5,074	-245 PJ (Gross inland consumption of elec. Equiv)		
Petroleum products	LPG [3220]	122	[nrg_102a]	[B_101800, B_102010, B_102030, B_1	Heat
	Naphta [3250]	0.0	[nrg_102a]	[B_101007]	Heat
	Gas/Diesel oil [3260]	451	[nrg_102a]	[B_101800, B_102010, B_102035]	Heat
	Residual Fuel Oil [3270A]	56	[nrg_102a]	[B_101800, B_102010, B_102030, B_1	Heat
	Other petroleum products [328	41	[nrg_102a]	[B_101800, B_102010, B_102030, B_1	Heat
Solid Fuels	Hard Coal and Patent Fuels [2	133	[nrg_101a]	[B_101004 - B_101020]	Heat
	Coke [2120]	43	[nrg_101a]	[B_101006]	Heat
Gas	Derived Gas [4200]	27	[nrg_103a]	[B_101700]	Heat
	Natural Gas [4100]	1,292	[nrg_103a]	[B_101400, B_101700]	Heat
Renewables	Solar Heat [5532]	2.16	[nrg_1071a]	[B_101700]	Heat
	Geothermal Energy [5550]	3.71	[nrg_1071a]	[B_101700]	Heat
	Biomass & Wastes [5540]	493	[nrg_1071a]	[B_101700]	Heat
	TOTAL	2,663			
	TOTAL	11,117			

Table 1: GER (Heat equivalent) per PES used in different EC Production (France, 2009). [Sources: Eurostat 2012, after Sorman 2011]

Then, it becomes possible to know (1) the mix of EC produced using a given PES category; and (2) the mix of PES used for generating each EC, as presented in Tables 2 and 3.

PES Category	ELEC	HEAT	FUEL	Σ
Petroleum products	0.01	0.16	0.83	1
Solid Fuels	0.55	0.45	0	1
Gas	0.17	0.83	0	1
Nuclear	1	0	0	1
Renewables	0.58	0.42	0	1

Table 2: Mix of EC per PES category (France, 2009).

PES Category	ELEC	HEAT	FUEL
Petroleum products	0.01	0.25	1
Solid Fuels	0.04	0.07	0
Gas	0.05	0.5	0
Nuclear	0.76	0	0
Renewables	0.13	0.19	0
Σ	1	1	1

Table 3: Mix of PES category per EC generated (France, 2009).

3.2 The EC-EU transformation

The transformation/translation of a given mix of Energy Carriers (EC) into a specified mix of End Uses (EU) is associated with the expression of societal functions taking place at different hierarchical levels – needed for the reproduction of society. The semantic category "End Uses" can be formalized using the various sectors of society. In particular, when discussing the viability of power-supply systems, it is necessary to provide information on the use of EC in the following sectors: (1) at level n, societal average (SA); (2) at level n-3, energy and mining (EM) and building and manufacturing (BM); (3) at level n-4, electricity production sector divided into two sub-sectors EM_{ELEC} (for the control of energy flows involved in the production of electricity) and BM_{ELEC} (for the making and maintenance of facilities used in the process of electricity generation).

In order to provide information on the amount of EC used per EU category, it is necessary to express the EC generated in units of EC (i.e. in MJ-EC). However, this implies knowing in advance the distribution of EC per every EU, e.g. how much Fuel is used in the BM sector. This is where resides the bifurcation in the protocol. Indeed, in order to solve the problem of impredicativity (mix of EC per EU needed to know the amount of EC used per EU), it is unavoidable to try to track what are the PES used to generate a certain amount of EC in a given EU. In order to do so, sit is first possible to identify the amount of Electricity used in society (in GWh or in MJ-EC) that corresponds to the net generation of electricity minus all the losses taking place before the EU. Then, the amount of Heat used in society can be evaluated by following the same logic of the net electricity generated minus all losses, for all PES categories used for making heat (known from Table 1). Finally, the amount of Fuel used in society can be evaluated following the same logic of net generation of fuels minus losses for the all petroleum products, except the ones used for heating purposes. Results on the amount of EC used in society is provided in Table 4.

EC	PES Category	PES (using Eurostat nomenclature)	PJ-EC	Table	Assumption	Indicators
Fuel	Petroleum products	Total petroleum products [3000]	2,629	[nrg_102a]	Net consumption MINUS losses	[B_101700] - [B_101300] - [B_101400]
		[3220, 3250, 3260, 3270A, 3280]	*-669*		*Except petroleum products used for heating purposes*	
		TOTAL	1,960			
Elec			1,429	[nrg_105a]		[17_107100] + [B_100900] - [B_101400] - [B101300] - [17_107302] + [17_107301]
		TOTAL	1,429			
Heat	Petroleum products	LPG [3220]	122	[nrg_102a]	no losses between PES and EC	[B_101800, B_102010, B_102030, B_102035]
		Naphta [3250]	0.0	[nrg_102a]	no losses between PES and EC	[B_101007]
		Gas/Diesel oil [3260]	451	[nrg_102a]	no losses between PES and EC	[B_101800, B_102010, B_102035]
		Residual Fuel Oil [3270A]	56	[nrg_102a]	no losses between PES and EC	[B_101800, B_102010, B_102030, B_102035]
		Other petroleum products [3280]	41	[nrg_102a]	no losses between PES and EC	[B_101800, B_102010, B_102030, B_102035]
Heat	Solid Fuels	Hard Coal and Patent Fuels [2112-2	89	[nrg_101a]	Net consumption MINUS losses	[B_101700] - [B_101300] - [B_101400]
		Coke [2120]	43	[nrg_101a]	Net consumption MINUS losses	[B_101700] - [B_101300] - [B_101400]
Heat	Gas	Derived Gas [4200]	13	[nrg_103a]	Net consumption MINUS losses	[B_101700] - [B_101300] - [B_101400]
		Natural Gas [4100]	1,182	[nrg_103a]	Net consumption MINUS losses	[B_101700] - [B_101300] - [B_101400]
Heat	Renewables	Solar Heat [5532]	2.16	[nrg_1071a]	no losses between PES and EC	[B_101700]
		Geothermal Energy [5550]	3.71	[nrg_1071a]	no losses between PES and EC	[B_101700]
		Biomass & Wastes [5540]	493	[nrg_1071a]	no losses between PES and EC	[B_101700]
		TOTAL	2,494			
		TOTAL	5,884			

Table 4: Total EC consumption, before iteration on HEAT (France, 2009).

From Table 4, we see that information on losses are not available for some products used for generating Heat. As a matter of fact, the evaluation of the amount of EC per EU requires an adjustment. This adjustment can be made by looking at the gross PES/EC ratio obtained between the PES-EC transformation (Table 1) and the EC-EU (Table 4, the EU category corresponding here to the societal average SA) as shown in Table 5.

Fuel	1.72
Elec	3.38
Heat	1.07

Table 5: PES/EC ratios, before iteration (France, 2009).

In fact, the PES/EC ratio will be used for the products used for heating purposed for which no information on losses can be found. By doing so the protocol assumes that the average transformation efficiency between PES and EC for making heat obtained with information available on partial products only is the same for other products used for heating purposes. Then, it becomes possible to get an iterated mix of EC used in society as presented in Table 6.

EC	PES Category	PES (using Eurostat nomenclature)	PJ-EC	Table	Assumption	Indicators
Fuel	Petroleum products	Total petroleum products [3000]	2,629	[nrg_102a]	Net consumption MINUS losses	[B_101700] - [B_101300] - [B_101400]
		[3220, 3250, 3260, 3270A, 3280]	*-627*		*Except petroleum products used for heating purposes*	
		TOTAL	2,003			
Elec			1,429	[nrg_105a]		[17_107100] + [B_100900] - [B_101400] - [B101300] - [17_107302] + [17_107301]
		TOTAL	1,429			
Heat	Petroleum products	LPG [3220]	114	[nrg_102a]	applying PES/EC ratio for HEAT to compensate for loss	[B_101800, B_102010, B_102030, B_102035]
		Naphta [3250]	0.0	[nrg_102a]	applying PES/EC ratio for HEAT to compensate for loss	[B_101007]
		Gas/Diesel oil [3260]	422	[nrg_102a]	applying PES/EC ratio for HEAT to compensate for loss	[B_101800, B_102010, B_102035]
		Residual Fuel Oil [3270A]	52	[nrg_102a]	applying PES/EC ratio for HEAT to compensate for loss	[B_101800, B_102010, B_102030, B_102035]
		Other petroleum products [3280]	38	[nrg_102a]	applying PES/EC ratio for HEAT to compensate for loss	[B_101800, B_102010, B_102030, B_102035]
Heat	Solid Fuels	Hard Coal and Patent Fuels [2112-21	89	[nrg_101a]	Net consumption MINUS losses	[B_101700] - [B_101300] - [B_101400]
		Coke [2120]	43	[nrg_101a]	Net consumption MINUS losses	[B_101700] - [B_101300] - [B_101400]
Heat	Gas	Derived Gas [4200]	13	[nrg_103a]	Net consumption MINUS losses	[B_101700] - [B_101300] - [B_101400]
		Natural Gas [4100]	1,182	[nrg_103a]	Net consumption MINUS losses	[B_101700] - [B_101300] - [B_101400]
Heat	Renewables	Solar Heat [5532]	2.02	[nrg_1071a]	applying PES/EC ratio for HEAT to compensate for loss	[B_101700]
		Geothermal Energy [5550]	3.47	[nrg_1071a]	applying PES/EC ratio for HEAT to compensate for loss	[B_101700]
		Biomass & Wastes [5540]	462	[nrg_1071a]	applying PES/EC ratio for HEAT to compensate for loss	[B_101700]
		TOTAL	2,421			
		TOTAL	5,852			

Table 6: Total EC consumption, after iteration on HEAT (France, 2009).

From the iterated mix of EC per EU category at societal level, it becomes possible to obtain the iterated PES/EC ratios for all EC forms (see Table 13).

Following the same logic, the mix of EC can be obtained for other EU, namely the EM and BM sectors as well as for the net imports at the societal level (IMP) making it possible to discuss the dependence of a country on foreign imports in comparison with domestic production (see Tables 7, 8 and 13).

EC	PES Category	PES (using Eurostat nomenclature)	PJ-EC	Table	Assumption	Indicators
Fuel	Petroleum products	Total petroleum products [3000]	2,829	[nrg_102a]	applying Net imports/PES ratio to EC net consumption	ET_{EC} * [B_100300 - B_101500] / ET_{PES}
		[3220, 3250, 3260, 3270A, 3280]	*-702*		*Except petroleum products used for heating purposes*	
		TOTAL	2,127			
Elec			-93.4	[nrg_105a]		[B_100300] - [B_100500]
		TOTAL	-93			
Heat	Petroleum products	LPG [3220]	63	[nrg_102a]	applying Net imports/PES ratio to EC net consumption	ET_{EC} * [B_100300 - B_101500] / ET_{PES}
		Naphta [3250]	0	[nrg_102a]	applying Net imports/PES ratio to EC net consumption	ET_{EC} * [B_100300 - B_101500] / ET_{PES}
		Gas/Diesel oil [3260]	582	[nrg_102a]	applying Net imports/PES ratio to EC net consumption	ET_{EC} * [B_100300 - B_101500] / ET_{PES}
		Residual Fuel Oil [3270A]	35	[nrg_102a]	applying Net imports/PES ratio to EC net consumption	ET_{EC} * [B_100300 - B_101500] / ET_{PES}
		Other petroleum products [3280]	22	[nrg_102a]	applying Net imports/PES ratio to EC net consumption	ET_{EC} * [B_100300 - B_101500] / ET_{PES}
Heat	Solid Fuels	Hard Coal and Patent Fuels [2112-21	279	[nrg_101a]	applying Net imports/PES ratio to EC net consumption	ET_{EC} * [B_100300 - B_101500] / ET_{PES}
		Coke [2120]	12	[nrg_101a]	applying Net imports/PES ratio to EC net consumption	ET_{EC} * [B_100300 - B_101500] / ET_{PES}
Heat	Gas	Derived Gas [4200]	0	[nrg_103a]	applying Net imports/PES ratio to EC net consumption	ET_{EC} * [B_100300 - B_101500] / ET_{PES}
		Natural Gas [4100]	1,486	[nrg_103a]	applying Net imports/PES ratio to EC net consumption	ET_{EC} * [B_100300 - B_101500] / ET_{PES}
Heat	Renewables	Solar Heat [5532]	0	[nrg_1071a]	applying Net imports/PES ratio to EC net consumption	ET_{EC} * [B_100300 - B_101500] / ET_{PES}
		Geothermal Energy [5550]	0	[nrg_1071a]	applying Net imports/PES ratio to EC net consumption	ET_{EC} * [B_100300 - B_101500] / ET_{PES}
		Biomass & Wastes [5540]	6	[nrg_1071a]	applying Net imports/PES ratio to EC net consumption	ET_{EC} * [B_100300 - B_101500] / ET_{PES}
		TOTAL	2,485			
		TOTAL	4,518			

Table 7: Net imports of EC consumption (France, 2009).

EC	PES Category	PES (using Eurostat nomenclature)	PJ-EC	Table	Assumption	Indicators
Fuel	Petroleum products	Total petroleum products [3000]	1,688	[nrg_102a]	- applying Industry consumption/PES ratio to EC net consumption	ET_{EC} * [B_101800 - B_101825 + B_101900] / ET_{PES}
		[3220, 3250, 3260, 3270A, 3280]	*-1,367*		- including fuel for Transportation (allocated to HH and SG *Except petroleum products used for heating purposes*	
		TOTAL	322			
Elec			445	[nrg_105a]		[B_101800 - B_101825 + B_101900]
		TOTAL	445			
Heat	Petroleum products	LPG [3220]	37	[nrg_102a]	applying Industry consumption/PES ratio to EC net consumptior	ET_{EC} * [B_101800 - B_101825 + B_101900] / ET_{PES}
		Naphta [3250]	0	[nrg_102a]	applying Industry consumption/PES ratio to EC net consumptior	ET_{EC} * [B_101800 - B_101825 + B_101900] / ET_{PES}
		Gas/Diesel oil [3260]	1,255	[nrg_102a]	applying Industry consumption/PES ratio to EC net consumptior	ET_{EC} * [B_101800 - B_101825 + B_101900] / ET_{PES}
		Residual Fuel Oil [3270A]	36	[nrg_102a]	applying Industry consumption/PES ratio to EC net consumptior	ET_{EC} * [B_101800 - B_101825 + B_101900] / ET_{PES}
		Other petroleum products [3280]	38	[nrg_102a]	applying Industry consumption/PES ratio to EC net consumptior	ET_{EC} * [B_101800 - B_101825 + B_101900] / ET_{PES}
Heat	Solid Fuels	Hard Coal and Patent Fuels [2112-21	49	[nrg_101a]	applying Industry consumption/PES ratio to EC net consumptior	ET_{EC} * [B_101800 - B_101825 + B_101900] / ET_{PES}
		Coke [2120]	75	[nrg_101a]	applying Industry consumption/PES ratio to EC net consumptior	ET_{EC} * [B_101800 - B_101825 + B_101900] / ET_{PES}
Heat	Gas	Derived Gas [4200]	13	[nrg_103a]	applying Industry consumption/PES ratio to EC net consumptior	ET_{EC} * [B_101800 - B_101825 + B_101900] / ET_{PES}
		Natural Gas [4100]	313	[nrg_103a]	applying Industry consumption/PES ratio to EC net consumptior	ET_{EC} * [B_101800 - B_101825 + B_101900] / ET_{PES}
Heat	Renewables	Solar Heat [5532]	0	[nrg_1071a]	applying Industry consumption/PES ratio to EC net consumptior	ET_{EC} * [B_101800 - B_101825 + B_101900] / ET_{PES}
		Geothermal Energy [5550]	0	[nrg_1071a]	applying Industry consumption/PES ratio to EC net consumptior	ET_{EC} * [B_101800 - B_101825 + B_101900] / ET_{PES}
		Biomass & Wastes [5540]	171	[nrg_1071a]	applying Industry consumption/PES ratio to EC net consumptior	ET_{EC} * [B_101800 - B_101825 + B_101900] / ET_{PES}
		TOTAL	1,987			
		TOTAL	2,754			

Table 8: EC consumption in the BM sector (France, 2009).

For End-Uses specific to the electricity production sector (EM_{ELEC} and BM_{ELEC}), it is possible to get information on the consumption of Electricity, Heat and Fuel within the EM sector per sub-process so that it can be allocated to the production of a EC category (Tables 9-11).

Production process	ELEC consumption (MJ-EC p.c.)	ELEC prod	HEAT prod	FUEL prod	Σ	Assumptions (when specified)
B_101300 - Consumption in Energy Sector	**3110**	***0.52***	***0.27***	***0.20***	***1***	***Weighted relatively to ELEC consumption in sub-processes***
B_101301 - Own Use in Electricity, CHP and Heat Plants	1348	0.66	0.34		1	Weighted relatively to GER for ELEC and HEAT production
B_101302 - Pumped storage power stations balance	103	1	0	0	1	Considering "Hydro Power" only
B_101305 - Consumption in Oil and gas extraction	28	0.09	0.5	0.41	1	Weighted relatively to GER of "Petroleum products" and "Gas"
B_101307 - Consumption in Petroleum Refineries	247	0.01	0.16	0.83	1	
B_101308 - Consumption in Nuclear industry	0	1	0	0	1	
B_101310 - Consumption in Coal Mines	3	0.61	0.39	0	1	Considering "Hard Coal and Patent Fuels" only
B_101311 - Consumption in Patent Fuel Plants	0	0.61	0.39	0	1	Considering "Hard Coal and Patent Fuels" only
B_101312 - Consumption in Coke Ovens	0	0	1	0	1	Considering "Coke" only
B_101313 - Consumption in BKB / PB Plants	0	0	0	0	0	Considering "Lignite and Deriv." only
B_101314 - Consumption in Gas Works	0	0.46	0.54	0	1	Considering "Derived Gas" only
B_101315 - Consumption in Blast Furnaces	0	0.46	0.54	0	1	Considering "Derived Gas" only
B_101316 - Consumption in Coal Liquefaction Plants	0			1	1	For FUEL production only
B_101317 - Consumption in Liquefaction (LNG) / regasifica	0	0.16	0.84	0	1	Considering "Natural Gas" only
B_101318 - Consumption in Gasification plants for biogas	0	0.11	0.89	0	1	Considering "Biomass & Wastes" only
B_101319 - Consumption in Gas-to-liquids (GTL) plants (e	0			1	1	For FUEL production only
B_101320 - Consumption in Non-specified (Energy)	1381	0.46	0.24	0.3	1	Weighted relatively to TGER
B_101321 - Consumption in Charcoal production plants (E	0	0.11	0.89	0	1	Considering "Biomass & Wastes" only
B_101322 - Used for heat pumps	0		1		1	For HEAT production only
B_101323 - Used for electric boilers	0		1		1	For HEAT production only

Table 9: ELEC consumption in EM sector per EC-type production process (France, 2009).

PES Category	PES (using Eurostat nomenclature)	HEAT consumption (MJ-EC p.c.)	ELEC prod	HEAT prod	FUEL prod	Σ	Assumptions (when specified)
Petroleum products	LPG [3220]	34	0	1	0	1	Weighted relatively to GER for ELEC and HEAT production
	Naphta [3250]	0	0	0	0	0	Weighted relatively to GER for ELEC and HEAT production
	Gas/Diesel oil [3260]	20	0.01	0.99	0	1	Weighted relatively to GER for ELEC and HEAT production
	Residual Fuel Oil [3270A]	260	0.44	0.56	0	1	Weighted relatively to GER for ELEC and HEAT production
	Other petroleum products [3280]	627	0	1	0	1	Weighted relatively to GER for ELEC and HEAT production
Solid Fuels	Hard Coal and Patent Fuels [2112-2118]	0	0.61	0.39	0	1	Weighted relatively to GER for ELEC and HEAT production
	Coke [2120]	1.8	0	1	0	1	Weighted relatively to GER for ELEC and HEAT production
Gas	Derived Gas [4200]	121	0.46	0.54	0	1	Weighted relatively to GER for ELEC and HEAT production
	Natural Gas [4100]	401	0.16	0.84	0	1	Weighted relatively to GER for ELEC and HEAT production
Renewables	Solar Heat [5532]	0	0	1	0	1	Weighted relatively to GER for ELEC and HEAT production
	Geothermal Energy [5550]	0	0	1	0	1	Weighted relatively to GER for ELEC and HEAT production
	Biomass & Wastes [5540]	0	0.11	0.89	0	1	Weighted relatively to GER for ELEC and HEAT production
	Total	***1466***	***0.16***	***0.84***	***0.00***	***1***	***Weighted relatively to HEAT consumption in sub-processes***

Table 10: HEAT consumption in EM sector per EC-type production process (France, 2009).

Fossil PES Category	FUEL consumption in Energy Sector [B_101300] (MJ-EC p.c.)	ELEC prod	HEAT prod	FUEL prod	Σ	Assumptions (when specified)
Petroleum products [3000], except [3220, 3250, 3260, 3270A, 3280]	2,061	0.01	0.16	0.83	1	From "Mix of EC per PES category" matrix

Table 11: FUEL consumption in EM sector per EC-type production process (France, 2009).

4. Getting Information on Labor for Electricity Production

National labor statistics of hours worked per economic activities are used until the 4-digit level so that it can be distributed among EC production categories (see details in Appendix A). Table 12 shows the total amount of hours worked for the production of electricity. Hours are allocated either to the EM sector (for the control of processes – energy flows), the BM sector (for the making and maintenance of facilities – fund elements) or the SG sector (for other activities like electricity distribution and regulations). Within the EM sector, labor is distributed considering the same standard unit operations that cover the overall processes of electricity production (more details can be found in Diaz-Maurin and Giampietro *forthcoming*): (1) Mining; (2) Refining/Enrichment; (3) Power generation; and (4) Handling waste / Controlling pollution.

Code	Description	ELEC					
		EM				BM	SG
		Mining	Refining	Operation	Waste		
05	Mining of coal and lignite						
05.10	Mining of hard coal	23,545	23,545				
05.20	Mining of lignite	0	0				
06	Extraction of crude petroleum and natural gas						
06.10	Extraction of crude petroleum	0					
06.20	Extraction of natural gas	0					
07	Extraction of crude petroleum and natural gas						
07.21	Mining of uranium and thorium ores	0					
08	Other mining and quarrying						
09.10	Support activities for petroleum and natural gas extraction	16,252					
09.90	Support activities for other mining and quarrying	62,148					
C	Manufacturing						
19.10	Manufacture of coke oven products		0				
19.20	Manufacture of refined petroleum products		0				
20.13	Manufacture of other inorganic basic chemicals						
20.13A (NAF Rev.2)	Enrichment of uranium and reprocessing of nuclear fuel		19,560,460		2,173,384		
24.46	Processing of nuclear fuel		10,636,141				
28.92	Manufacture of machinery for mining, quarrying and construction					2,351,828	
35.1	Electric power generation, transmission and distribution			N/A			N/A
35.11	Production of electricity			123,340,029			
35.12	Transmission of electricity						15,831,805
35.13	Distribution of electricity						78,205,539
35.14	Trade of electricity						3,235,763
35.2	Manufacture of gas; distribution of gaseous fuels through mains			N/A			N/A
35.21	Manufacture of gas			11,594			
35.22	Distribution of gaseous fuels through mains						2,522,335
35.23	Trade of gas through mains						2,323,160
35.3	Steam and air conditioning supply						
38.12	Collection of hazardous waste				77,670,461		
38.22	Treatment and disposal of hazardous waste				11,690,976		
F	Construction						
42	Civil engineering						
42.22	Construction of utility projects for electricity and telecommunications					43,816,964	
49.20	Freight rail transport						0
49.41	Freight transport by road						0
49.50	Transport via pipeline						1,188,067
50.20	Sea and coastal freight water transport						0
	TOTAL:	**102,000**	**30,221,000**	**123,352,000**	**91,535,000**	**46,169,000**	**103,307,000**

Table 12: Total hours worked in the electricity production per economic activities (France, 2009). Note: The evaluation of labor per EC production category considers the assumptions presented in Appendix B.

5. Assessing power-supply systems in relation to internal constraints

5.1 Multi-level matrix on the consumption side

Table 13 presents the following benchmarks for each one of the sectors (i) presented in Section 3.2 (see also Giampietro et al. 2012, Sorman 2011):

- $ET_{PES,i}$ – energy throughput in the form of PES (measured in joules of PES p.c./y or Gross Energy Requirement p.c./y);
- $y_{j,i}$ – PES/EC ratio throughput per EC category (j);
- $ET_{EC,i}$ – energy throughput in the form of EC (measured in joules of EC p.c./y);
- $x_{j,i}$ – fraction of each EC category (j) per unit of $ET_{EC,i}$;
- HA_i – human activity (measured in hours p.c./y);
- $EMR_{EC,i}$ – exosomatic metabolic rate equals to $ET_{EC,i}$ / Ha_i (measured in MJ-EC per hour);
- $PC_i = \Sigma\ PC_{j,i}$ – power capacity (measured in kW per capita).

		Flows of PES				*Flows of EC*					*Flow/Fund*	*Fund-endo*	*Fund-exo*				
		PES	PES/EC			Net EC		Carriers mix			Power level	Human activity	Total power capacity	Elec	Heat	Fuel	
General vector	*[*	*$ET_{PES,i}$*	*$y_{1,i}$*	*$y_{2,i}$*	*$y_{3,i}$*	*τ_i*	*$ET_{EC,I}$*	*$x_{e,i}$*	*$x_{h,i}$*	*$x_{f,i}$*	*$EMR_{EC,i}$*	*HA_i*	*PC_i*	*$PC_{e,i}$*	*$PC_{h,i}$*	*$PC_{f,i}$*	*]*
Compartment		*GJ p.c./y*	*(elec)*	*(heat)*	*(fuel)*		*GJ p.c./y*	*(elec)*	*(heat)*	*(fuel)*	*$MJ/h_{(EC)}$*	*hours p.c./y*	*kW p.c./y*	*kW p.c./y*	*kW p.c./y*	*kW p.c./y*	*Level*
SA	[	173	3.55	1.10	1.69	1	91	0.24	0.41	0.34	10.4	8,760	-	-	-	-	] *n*
IMP [(a)]	[	93	3.55	1.10	1.69	0.77	70	-0.021	0.55	0.47	8.0	8,760	-	-	-	-	] *n*
EM [(b)]	[	16.1	3.55	1.10	1.69	0.07	6.6	0.47	0.22	0.31	1,555	4.3	0.177	0.105 (f)	0.050 (f)	0.022 (g)	] *n-3*
BM [(c)]	[	67	3.55	1.10	1.69	0.47	43	0.16	0.72	0.12	342	125	1.3	0.234 (f)	1.045 (f)	0.053 (g)	] *n-3*
EM_{ELEC} [(d)]	[	6.1	3.55	1.10	1.69	0.021	1.88	0.86	0.12	0.01	493	3.8	0.063	0.055 (f)	0.008 (f)	0.000 (g)	] *n-4*
BM_{ELEC} [(d)]	[	-	-	-	-	-	not available	not available	not available	not available	-	0.72	-	-	-	-	] *n-4*

Table 13: Production factors on the demand side (France, 2009).

Notes: (a) Equivalent control of energy flows (processes) for the consumption of EC from Net Imports; (b) Control of energy flows (processes); (c) Making and maintenance of fund elements (facilities), including transportation (allocated to HH and SG sectors in Sorman 2011); (d) Control of energy flows (processes) for the production of electricity from domestic supply; (e) Making and maintenance of fund elements (facilities) for the production of electricity from domestic supply; (f) Assuming 80% of efficiency at 75% utilization factor; (g) Assuming 25% of efficiency at 75% utilization factor. For more details on the calculations of PC, see Diaz-Maurin and Giampietro *forthcoming*.

5.2 Production factors on the supply side

Production factors – e.g input of EC, input of labor, input of power capacity – characterizing the performance of power-supply systems (whose processes are taking place at level n-5) are presented in Table 14.

Parameters	Input of Energy Carriers (electricity)				Input of Energy Carriers (fossil-fuels)				Input of Labor				Input of Power Capacity				
	Direct IEC_I (control of flows)		*Indirect IEC_I (making/maintenance of funds)*		*Direct IEC_I (control of flows)*		*Indirect IEC_I (making/maintenance of funds)*		*Direct IL_I (control of flows)*		*Indirect IL_I (making/maintenance of funds)*		*PC_I direct (control of flows)*		*PC_I indirect (making/maintenance of funds)*		
Power Supply Systems	*MWh/GWh*		*MWh/GWh*		*GJ/GWh*		*GJ/GWh*		*h/GWh*		*h/GWh*		*kW/GWh*		*kW/GWh*		
	mean	*error*	*mean*	*error*	*mean*	*error*	*mean*	*error*	*mean*	*error*	*mean*	*error*	*mean*	*error*	*mean*	*error*	*Level*
FOSSIL (IGCC)	3.2	-	0.32	-	160	-	2.3	-	65	-	15	-	2.6	-	0.04	-	*n-5*
FOSSIL (IGCC w/ CCS)	120	± 6	0.32	-	210	-	4.0	-	87	-	28	-	2.8	-	0.05	-	*n-5*
NUCLEAR (LWR)	33	± 0.4	-	-	250	± 130	110	± 9	480	-	160	-	4.1	± 2.1	1.8	± 0.1	*n-5*
NUCLEAR (LWR w/ Reprocessing)	34	± 0.4	-	-	480	± 130	100	± 9	410	-	160	-	7.9	± 2.1	1.6	± 0.1	*n-5*

Table 14: Production factors on the supply side (France, 2009).
[Source: Diaz-Maurin and Giampietro *forthcoming*]

5.3 Crossing TOP-DOWN and BOTTOM-UP information

Figure 1 illustrates the general principle used to assess the viability of power-supply systems.

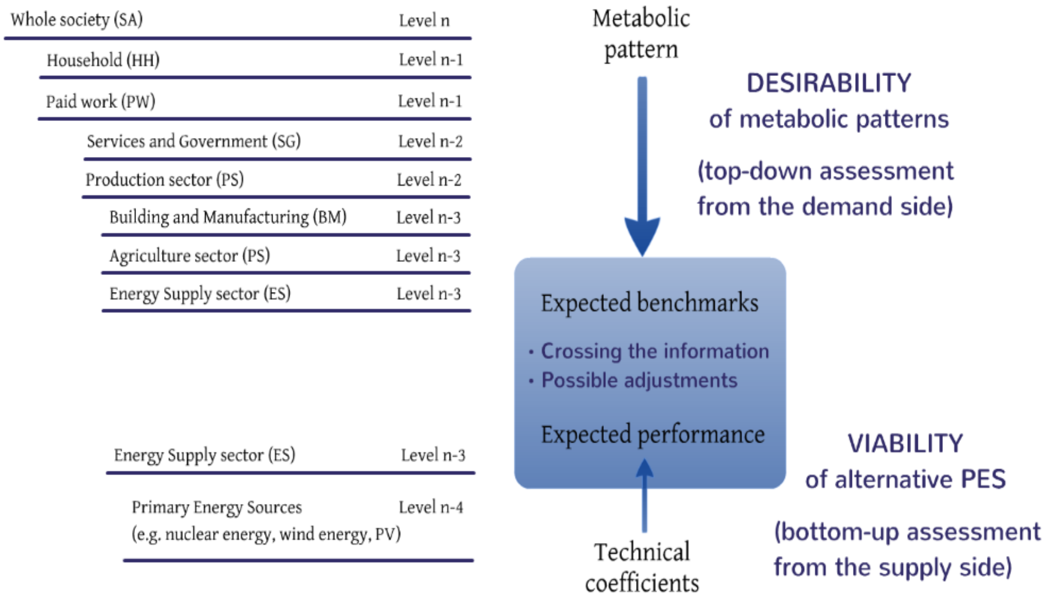


Figure 1: Crossing information between supply side and demand side – General principle

Finally in Table 15, we provide an example of assessment of the viability of nuclear energy and fossil energy used for the production of electricity in France for the year 2009.

TOP-DOWN assessment of benchmarks				BOTTOM-UP assessment of benchmarks			
Total net electricity generation	515	TWh	vs.	1		GWh	Net supply of EC (electricity)
ET_{EC} in EM_{ELEC}	235	GJ/GWh	vs.	172	-	GJ/GWh	Direct IEC_{FOSSIL} (IGCC)
				642	-	GJ/GWh	Direct IEC_{FOSSIL} (IGCC+CCS)
				369	± 131	GJ/GWh	Direct $IEC_{NUCLEAR}$ (LWR)
				602	± 131	GJ/GWh	Direct $IEC_{NUCLEAR}$ (LWR+Reproc.
ET_{EC} in BM	5,346	GJ/GWh	vs.	3.5	-	GJ/GWh	Indirect IEC_{FOSSIL} (IGCC)
				5	-	GJ/GWh	Indirect IEC_{FOSSIL} (IGCC+CCS)
				110	± 9	GJ/GWh	Indirect $IEC_{NUCLEAR}$ (LWR)
				100	± 9	GJ/GWh	Indirect $IEC_{NUCLEAR}$ (LWR+Repro
Labor in EM_{ELEC}	476	h/GWh	vs.	65	-	h/GWh	Direct IL_{FOSSIL} (IGCC)
				87	-	h/GWh	Direct IL_{FOSSIL} (IGCC+CCS)
				480	-	h/GWh	Direct $IL_{NUCLEAR}$ (LWR)
				410	-	h/GWh	Direct $IL_{NUCLEAR}$ (LWR+Reproc.)
Labor in BM_{ELEC}	90	h/GWh	vs.	15	-	h/GWh	Direct IL_{FOSSIL} (IGCC)
				28	-	h/GWh	Direct IL_{FOSSIL} (IGCC+CCS)
				160	-	h/GWh	Direct $IL_{NUCLEAR}$ (LWR)
				160	-	h/GWh	Direct $IL_{NUCLEAR}$ (LWR+Reproc.)
PC in EM_{ELEC}	7.9	kW/GWh	vs.	2.6	-	h/GWh	Direct PC_{FOSSIL} (IGCC)
				2.8	-	h/GWh	Direct PC_{FOSSIL} (IGCC+CCS)
				4.1	± 2.1	h/GWh	Direct $PC_{NUCLEAR}$ (LWR)
				7.9	± 2.1	h/GWh	Direct $PC_{NUCLEAR}$ (LWR+Reproc.,
PC in BM	166	kW/GWh	vs.	0.04	-	h/GWh	Indirect PC_{FOSSIL} (IGCC)
				0.05	-	h/GWh	Indirect PC_{FOSSIL} (IGCC+CCS)
				1.8	± 0.1	h/GWh	Indirect $PC_{NUCLEAR}$ (LWR)
				1.6	± 0.1	h/GWh	Indirect $PC_{NUCLEAR}$ (LWR+Reproc

Table 15: Crossing benchmark values (TOP-DOWN assessment) vs. production factors (BOTTOM-UP assessment) (France, 2009).

6. Conclusion

Using this protocol it becomes possible to discuss the viability of different power-supply systems for which the technical coefficients have to be evaluated following the grammar proposed by Diaz-Maurin and Giampietro *forthcoming*. In fact, by using this protocol it becomes possible to link assessments of technical coefficients performed at the level of the power-supply systems with assessments of benchmark values performed at the societal level throughout the relevant different sectors.

In particular, the example provided here in the case of France for the year 2009 makes it possible to see that in fact nuclear energy is not viable in terms of labor requirements (both direct and indirect inputs) as well as in terms of requirements of power capacity, especially when including reprocessing operations. This kind of situation – where an energy source that is largely used in one country appearing as not viable in certain biophysical terms – is made possible when other energy sources with higher performance compensate for the biophysical costs. In France, one can think of hydro power – an energy source seemingly much less labor and capital intensive than nuclear energy – compensating for the biophysical requirements implied by the extensive use of nuclear power in that country.

References

Diaz-Maurin, F. and Giampietro, M. A "Grammar" for Assessing the Performance of Power-Supply Systems, *Energy*. forthcoming

Giampietro, M. and Sorman, A.H. (2012) *Are energy statistics useful for making energy scenarios?*, Energy 37(1):5–17. doi:10.1016/j.energy.2011.08.038

Giampietro, M., Mayumi, K. and Sorman, A.H. (2012) *Energy Analysis for a Sustainable Future: Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism*, Routledge, Taylor & Francis Group, London

Sorman, A.H. (2011). *The energetics metabolisms of society. Development of Methodological Tools and Empirical Applications.* PhD Dissertation presented at Autonomous University of Barcelona. July 2011.

Appendix A: Data requirement for the calculations of the viability protocol

A1. *Data requirements on energy quantities*

To proceed with the protocol, initially the following data are required to download. These can easily be accessible from the Eurostat webpage (http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/), via the following steps:

1. Select statistical database (in left-column menu): http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database

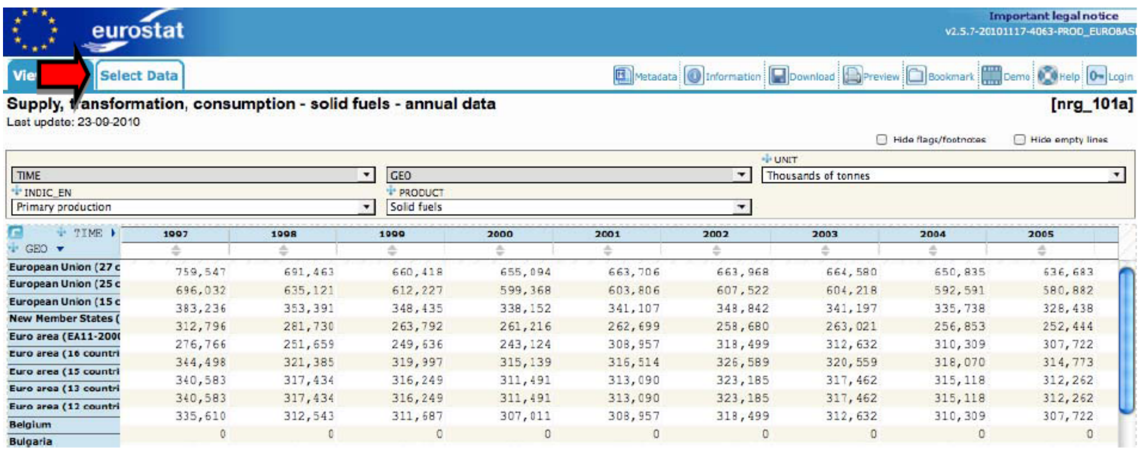
2. Proceed to the following navigation to reach the tables needed for the protocol: Data Navigation Tree → Database by themes → Environment and energy → Energy (nrg) → Energy Statistics - quantities (nrg_quant) → Energy Statistics - supply, transformation, consumption (nrg_10).

3. Select the following tables within the "nrg_10" category and download the following databases of information:
   - Supply, transformation, consumption - solid fuels - annual data (nrg_101a)
   - Supply, transformation, consumption - oil - annual data (nrg_102a)
   - Supply, transformation, consumption - gas - annual data (nrg_103a)
   - Supply, transformation, consumption - electricity - annual data (nrg_105a)
   - Supply, transformation, consumption - renewables and wastes (total, solar heat, biomass, geothermal, wastes) - annual data (nrg_1071a)
   - Supply, transformation, consumption - renewables (hydro, wind, photovoltaic) - annual data (nrg_1072a)

Note: Those tables of energy statistics constitute the following first 6 tabs tab out of the 8 tabs of input data forming the calculation sheet of this protocol.

For the scope of this analysis, the focal point is to gather data by PES source data based on annual consumption (rather than monthly tracked series, unless otherwise). Therefore, data only on annual consumption values are required.

Once each category is clicked, the window should look as follows:


eurostat
Important legal notice
v2.5.7-20101117-4063-PROD_EUROBASE
Vie Select Data
Metadata Information Download Preview Bookmark Demo Help Login
Supply, transformation, consumption - solid fuels - annual data [nrg_101a]
Last update: 23-09-2010
Hide flags/footnotes Hide empty lines
TIME | GEO | UNIT: Thousands of tonnes
INDIC_EN: Primary production | PRODUCT: Solid fuels

GEO \ TIME	1997	1998	1999	2000	2001	2002	2003	2004	2005
European Union (27 c	759,547	691,463	660,418	655,094	663,706	663,968	664,580	650,835	636,683
European Union (25 c	696,032	635,121	612,227	599,368	603,806	607,522	604,218	592,591	580,882
European Union (15 c	383,236	353,391	348,435	338,152	341,107	348,842	341,197	335,738	328,438
New Member States (	312,796	281,730	263,792	261,216	262,699	258,680	263,021	256,853	252,444
Euro area (EA11-200(	276,766	251,659	249,636	243,124	308,957	318,499	312,632	310,309	307,722
Euro area (16 countri	344,498	321,385	319,997	315,139	316,514	326,589	320,559	318,070	314,773
Euro area (15 countri	340,583	317,434	316,249	311,491	313,090	323,185	317,462	315,118	312,262
Euro area (13 countri	340,583	317,434	316,249	311,491	313,090	323,185	317,462	315,118	312,262
Euro area (12 countri	335,610	312,543	311,687	307,011	308,957	318,499	312,632	310,309	307,722
Belgium	0	0	0	0	0	0	0	0	0
Bulgaria									

Table A.1: The Eurostat data selection page

Under each Supply, transformation, consumption database for each product, on the upper left corner, it is possible to select data according to custom needs.

1. One can define in the "GEO" tab the geographic extent according to the country/region that is to be analyzed (see Fig. A.1) – select ALL for our protocol.

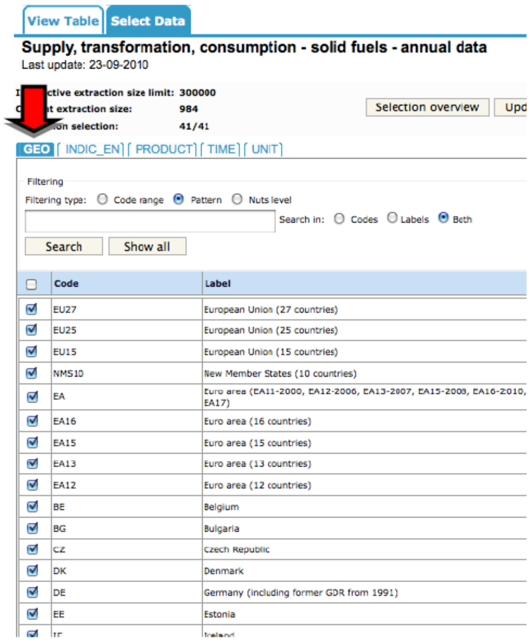


Figure A.1: Geographic location selection

2. Under the second “INDIC_EN” tab it is possible to select all relevant indicators representing the processes taking place (see Fig. A.2) – select ALL for our protocol.

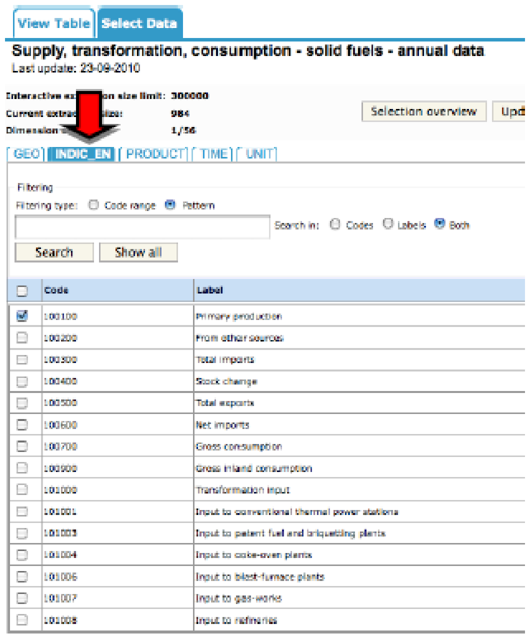


Figure A.2: Indicators for energy balance selection

3. In the third “PRODUCT” tab it is possible to get information on all the sub-product associated with a given category (see Fig. A.3) – select ALL for our protocol.

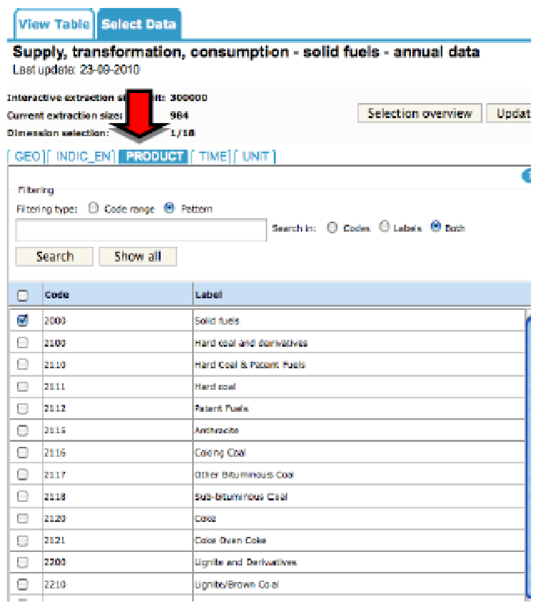


Figure A.3: Product selection

4. Depending on the time period of analysis, the preferred years can be selected for the required data using the “TIME” tab.

5. Lastly, under the “UNIT” tab, one can information on different forms of emergy expressed in different units (biophysical units and converted “joules”). In our protocol, we consider the following units for each main product category:

- Solid Fuels, Oil, Gas and Renewables and Wastes (total, solar heat, biomass, geothermal wastes): net calorific value (in TJ);
- Electricity, Renewables (hydro, wind, photovoltaic): electricity (in GWh).

A.2 Data requirements on labor

The protocol requires data on labor (total hours worked) distributed within economic category in relation to energy transformation (control of flows) and construction of facilities needed for the energy systems to operate (making and maintenance of funds). The Eurostat database referring to this information can be found using the following sequence:
Data Navigation Tree → Database by themes → Population and social conditions → Labour market (labour) → Employment and unemployment (Labour Force Survey (employ) → LFS series - Detailed annual survey results (lfsa) → Employment - LFS series (lfsa_emp) → Employment by sex, age and detailed economic activity (from 2008, NACE Rev.2 two digit level) (1 000) (lfsa_egan22d).

However, the Eurostat database only provides information until the second digit level (Sections) of the NACE Rev. 2 statistical classification of economic activities (e.g. for the category "05. Mining of coal and lignite", while in our protocol data are needed at a lower level in order to be compatible with the level of refinement of the energy data used. For this reason, our protocol requires using data from national statistics which Eurostat's database is based on and that provides a higher level of refinement (e.g. data on "05.10 Mining of hard coal" and "05.20 Mining of lignite"). For instance, we used the data provided by the French national statistics INSEE which provides information until the fourth digit level (Classes) using the NAF Rev. 2, 2008 that is the French equivalent to the NACE european nomenclature. The same information can be obtained for every european country following the NACE nomenclature. At the World level, it is also possible to obtain comparable information in countries using the LABORSTA database from the OECD/ILO that follows the ISIC nomenclature for which tables of equivalence with other nomenclatures (e.g. NACE) do exist.

Note: This information on labor statistics constitute the "Labor-data" tab out of the 8 tabs of input data forming the calculation sheet of this protocol.

A.3 Data requirements on population

Data on population can be found in the same Eurostat database as for energy statistics using the following sequence:
Data Navigation Tree → Database by themes → Population and social conditions → Population (populat) → Demography (pop) → Demography - National data (demo) → Population (demo_pop) → Population on 1 January by age and sex (demo_pjan).

This gives us the total population in a given country (selected under the "GEO" tab) as of 1st of January of a given year (selected under the "TIME" tab).

Note: This information on population statistics constitute the "Population" tab out of the 8 tabs of input data forming the calculation sheet of this protocol.

Appendix B: Assumptions on distribution of labor per economic activities

Distribution of labor per economic activities related to the production of EC as shown in Table 12 considers the following assumptions.

Code	Description	No specific to one EC						Specific to one EC or more							Assumptions #1
								ELEC			HEAT		FUEL		
		EM						EM			EM		EM		
		Mining	Refinir	Operat	Waste	BM	SG	Operat	BM	SG	Operat	SG	Operat	SG	
05	Mining of coal and lignite														See sub-categories
05.10	Mining of hard coal	50%	50%												Mining and Refining are mixed in Diaz-Maurin and Giampietro 2012
05.20	Mining of lignite	50%	50%												Mining and Refining are mixed in Diaz-Maurin and Giampietro 2012
06	Extraction of crude petroleum and natural gas														See sub-categories
06.10	Extraction of crude petroleum	100%													
06.20	Extraction of natural gas	100%													
07	Extraction of crude petroleum and natural gas														See sub-categories
07.21	Mining of uranium and thorium ores	100%													
08	Other mining and quarrying														Not allocated
09.10	Support activities for petroleum and natural gas extraction	100%													
09.90	Support activities for other mining and quarrying	100%													Mining activities (05.10, 05.20, 06.10, 06.20 and 07.21) compared to Total mining and quarrying activities (05, 06, 07 and 08).
C	Manufacturing														Not allocated
19.10	Manufacture of coke oven products		100%												
19.20	Manufacture of refined petroleum products		100%												
20.13	Manufacture of other inorganic basic chemicals														Not allocated unless data at lower level 20.13A (NAF Rev.2) is available
20.13A (NAF Rev.2)	Enrichment of uranium and reprocessing of nuclear fuel		90%		10%										100% of hazardeous waste considered as nuclear waste if country has Reprocessing facilities; or 0% otherwise. Then, distribution between "Refining" and "Handling waste" equal to 90%-10% (Diaz-Maurin and Giampietro, 2012).
24.46	Processing of nuclear fuel		100%												100% of hazardeous waste considered as nuclear waste if country has Reprocessing facilities; or 0% otherwise
28.92	Manufacture of machinery for mining, quarrying and construction					14%									Relative contribution of Mining activities (05.10, 05.20, 06.10, 06.20 and 07.21) and Construction of utility projects (42.22) to Total mining and quarrying activities (05, 06, 07 and 08) and Civil engineering (42)
35.1	Electric power generation, transmission and distribution							0%		0%					(d): If data is not available at level lower than 35.1, Operation-SG distribution considered as 40%-60%; 0% otherwise
35.11	Production of electricity							100%							
35.12	Transmission of electricity									100%					
35.13	Distribution of electricity									100%					
35.14	Trade of electricity									100%					
35.2	Manufacture of gas; distribution of gaseous fuels through mains			0%			0%								If data is not available at level lower than 35.2, Operation-SG distribution considered as 0%-100% (for non producers); 0% otherwise
35.21	Manufacture of gas			100%											
35.22	Distribution of gaseous fuels through mains						100%								
35.23	Trade of gas through mains						100%								
35.3	Steam and air conditioning supply										60%	40%			Operation-SG distribution considered as 60%-40%
38.12	Collection of hazardous waste				100%										100% of hazardeous waste considered as nuclear waste if country has Reprocessing facilities; or 0% otherwise
38.22	Treatment and disposal of hazardous waste				100%										100% of hazardeous waste considered as nuclear waste if country has Reprocessing facilities; or 0% otherwise
F	Construction														Not allocated
42	Civil engineering														Not allocated
42.22	Construction of utility projects for electricity and telecommunications								100%						
49.20	Freight rail transport						0%								Solid fuels in Total freight rail transport (NOT ALLOCATED HERE)
49.41	Freight transport by road						0%								Refined Petroleum products, Uranium ore and Nuclear fuel in Total freight transport by road (NOT ALLOCATED HERE)
49.50	Transport via pipeline						100%								
50.20	Sea and coastal freight water transport						0%								Crude Oil in Total freight transport by sea (NOT ALLOCATED HERE)

Table B.1: Distribution of economic activities per Unit Operations (France, 2009).

		EC			
Code	**Description**	**ELEC**	**HEAT**	**FUEL**	**Assumptions #2**
05	Mining of coal and lignite				See sub-categories
05.10	Mining of hard coal	0.61	0.39	0	Considering “Hard Coal and Patent Fuels” only
05.20	Mining of lignite	0	0	0	Considering “Lignite and Deriv.” only
06	Extraction of crude petroleum and natural gas				See sub-categories
06.10	Extraction of crude petroleum	0.01	0.16	0.83	Considering “Petroleum products”
06.20	Extraction of natural gas	0.16	0.84	0	Considering “Natural Gas” only
07	Extraction of crude petroleum and natural gas				See sub-categories
07.21	Mining of uranium and thorium ores	1	0	0	Considering “Nuclear”
08	Other mining and quarrying				Not allocated
09.10	Support activities for petroleum and natural gas extraction	0.05	0.35	0.6	Considering “Petroleum products” and “Natural Gas”
09.90	Support activities for other mining and quarrying	0.96	0.04	0	Considering “Solid Fuels” and “Nuclear”
C	Manufacturing				Not allocated
19.10	Manufacture of coke oven products	0	1	0	Considering “Coke” only
19.20	Manufacture of refined petroleum products	0.07	0.93	0	Considering “Refined Petroleum products” only
20.13	Manufacture of other inorganic basic chemicals				Not allocated unless data at lower level 20.13A (NAF Rev.2) is available
20.13A (NAF Rev.2)	Enrichment of uranium and reprocessing of nuclear fuel	1	0	0	Considering “Nuclear”
24.46	Processing of nuclear fuel	1	0	0	Considering “Nuclear”
28.92	Manufacture of machinery for mining, quarrying and construction	0.96	0.04	0	Considering “Solid Fuels” and “Nuclear”
35.1	Electric power generation, transmission and distribution	1	0	0	
35.11	Production of electricity	1	0	0	
35.12	Transmission of electricity	1	0	0	
35.13	Distribution of electricity	1	0	0	
35.14	Trade of electricity	1	0	0	
35.2	Manufacture of gas; distribution of gaseous fuels through mains	0.17	0.83	0	Considering “Gas”
35.21	Manufacture of gas	0.17	0.83	0	Considering “Gas”
35.22	Distribution of gaseous fuels through mains	0.17	0.83	0	Considering “Gas”
35.23	Trade of gas through mains	0.17	0.83	0	Considering “Gas”
35.3	Steam and air conditioning supply	0	1	0	
38.12	Collection of hazardous waste	1	0	0	Considering “Nuclear” only
38.22	Treatment and disposal of hazardous waste	1	0	0	Considering “Nuclear” only
F	Construction				Not allocated
42	Civil engineering				Not allocated
42.22	Construction of utility projects for electricity and telecommunications	1	0	0	
49.20	Freight rail transport	0.55	0.45	0	Considering “Solid Fuels” only
49.41	Freight transport by road	0.85	0.15	0	Considering “Refined Petroleum products” and “Nuclear” only
49.50	Transport via pipeline	0.17	0.83	0	Considering “Gas” only
50.20	Sea and coastal freight water transport	0.01	0.16	0.83	Considering “Petroleum products” only

Table B.2: Distribution of corresponding PES between EC (France, 2009).