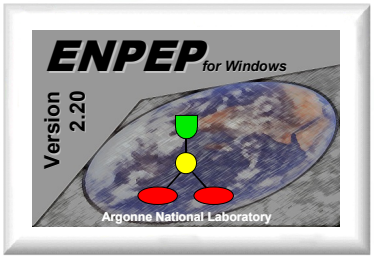
Environmental Calculations in ENPEP-BALANCE

ENPEP-BALANCE Training Course
Singapore
December 5-9, 2011



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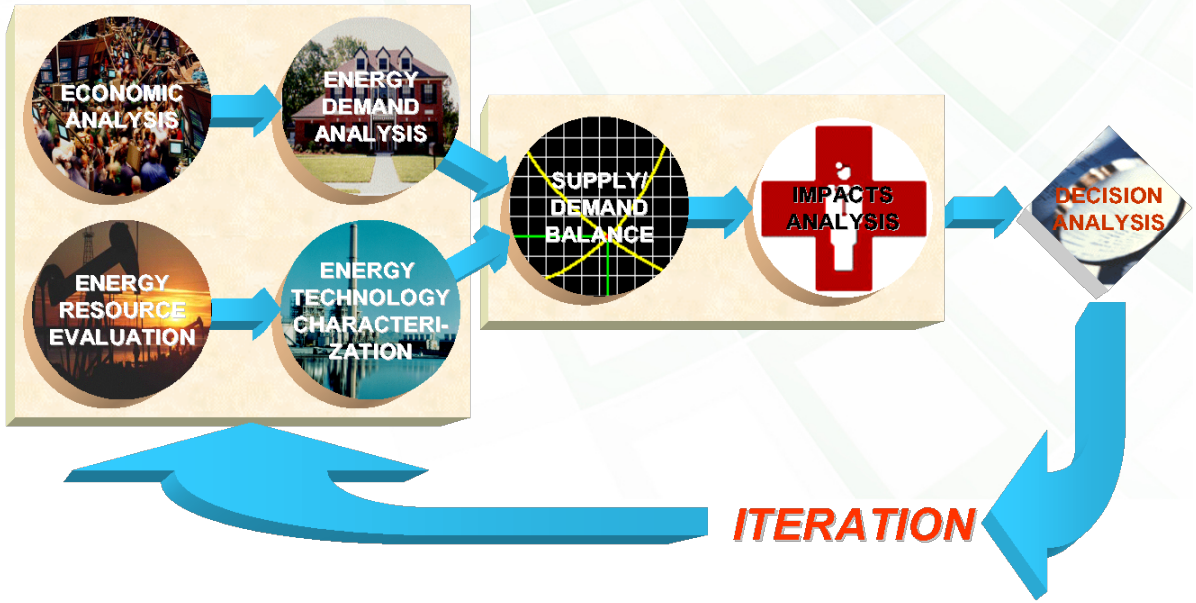
In General, there are Several Ways to do an Environmental Analysis

- "Optimize" energy, economics, and environment
  - Very complex
  - Results not as transparent
  - Too many assumptions ("black box")

- Maximize environmental "benefit"
  - Often too expensive to implement

- Design economic energy system, then iterate to meet environmental requirements
  - Resembles decision making process
  - Approach used in ENPEP



Main Design Characteristics for Environmental Calculations

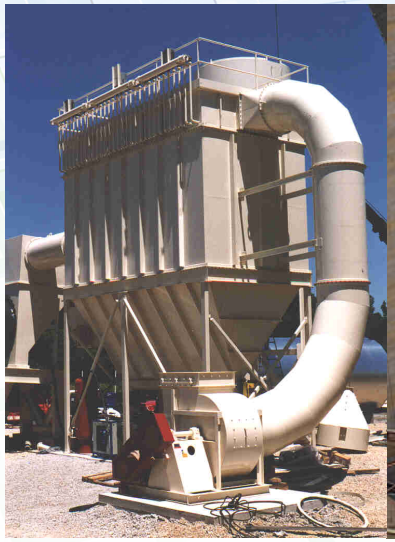
- Compute annual levels of atmospheric emissions from energy production, conversion, and consumption
- Implement emissions taxes (e.g., carbon tax) and examine the resulting changes in the energy supply mix and overall emission levels
- Introduce emission control technologies (e.g., electrostatic filters, flue gas desulfurization, DeNox, etc.) and analyze their effect on mitigating pollution levels (++)
  - Compute emissions after control
  - Compute avoided emissions
  - Compute incremental control costs including capital and O&M cost
  - Compute cost-effectiveness of emission controls
  - Update price/cost of output link of process
- Implement emissions limits and examine emissions trading, e.g. cap and trade (++)

(++) **Currently not implemented**

Emissions are Assumed to be a Function of the Following General Parameters

- Level of fuel consumption
- Type of fuel (e.g., coal versus oil versus gas, high sulfur coal versus low sulfur coal)
- Type of combustion technology (steam turbine versus gas turbine, pulverized coal versus stoker furnace, etc.)
- Type of pollution control equipment

ENPEP Uses a Standard Methodology to Determine the Uncontrolled and Controlled Source Emissions

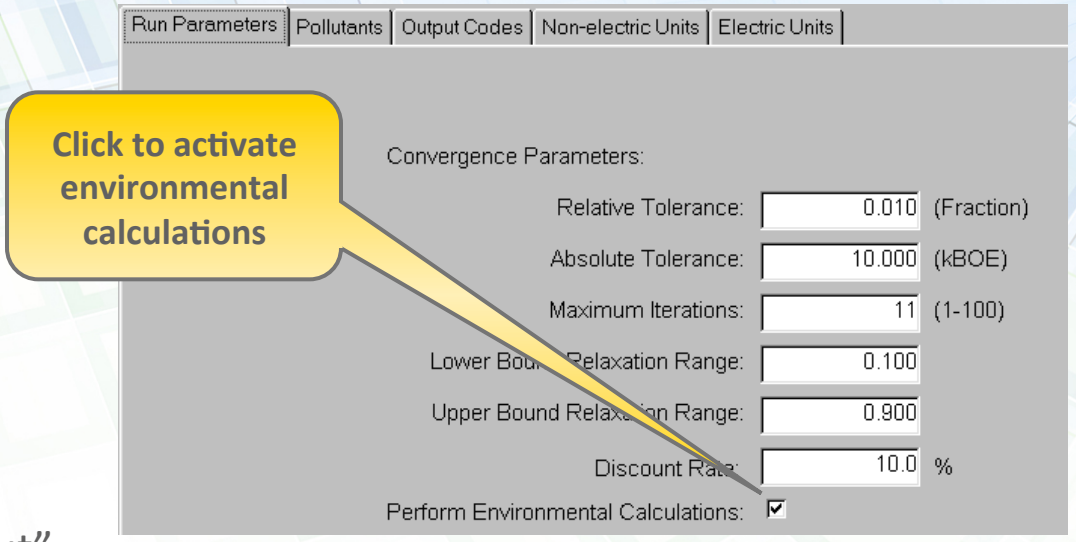


Uncontrolled Emissions = Fuel Consumption x Emission Factor x Chemical Scale

Controlled Emissions = Uncontrolled Emissions x (100 - Control Efficiency) / 100

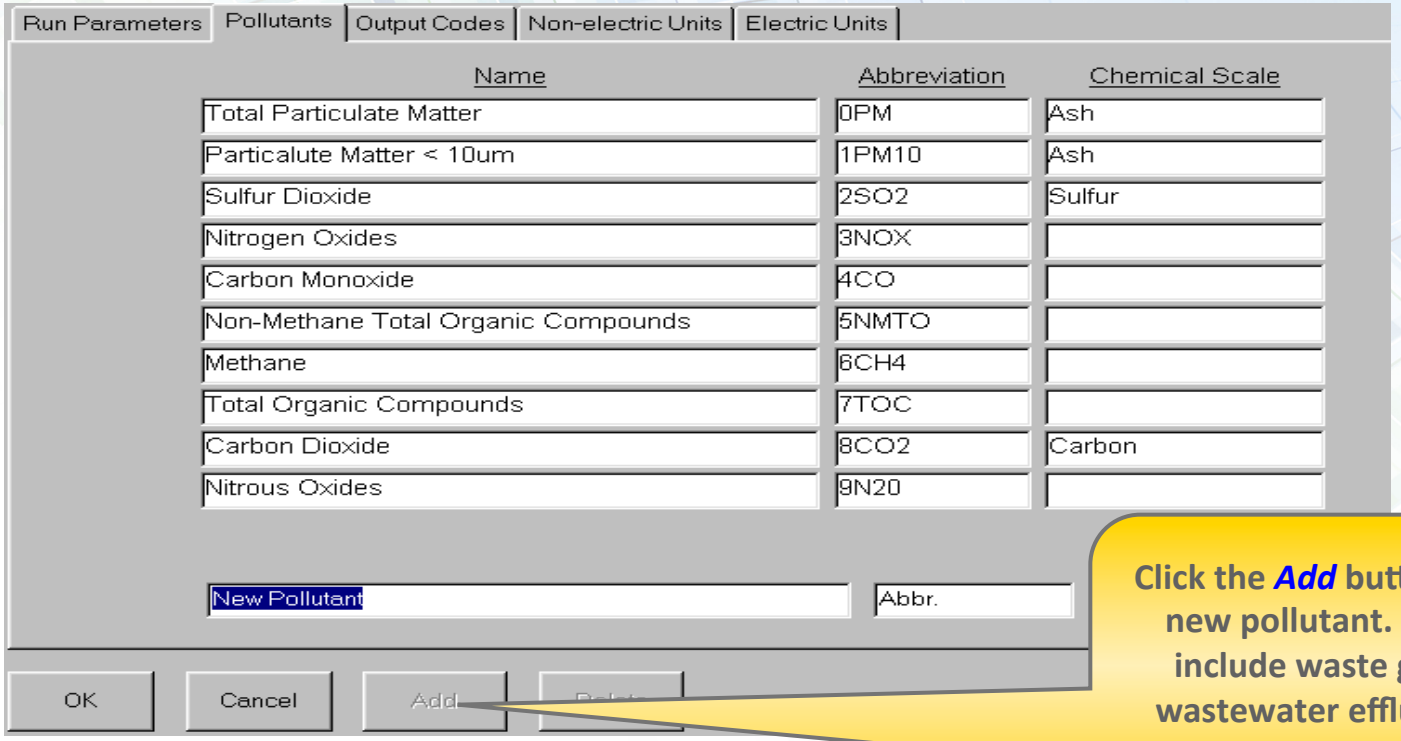
The Environmental Calculations Can be Activated under Run Parameters

- Checking the "Perform Environmental Calculations" box will activate the environmental routines



- After activating, the user has access to the environmental input data screens as well as the output screens
  - If not activated, the environmental input/output screens are "greyed-out" to indicate they are NOT accessible
- After entering all environmental information and running the case, the user can turn the environmental calculations off again by unchecking this box
  - Speeds up the calculations; useful if BALANCE-energy is not finalized yet
  - Environmental information (inputs and results) is maintained in the database but no calculations are performed
  - Environmental calculations can be turned back on again by re-checking the box

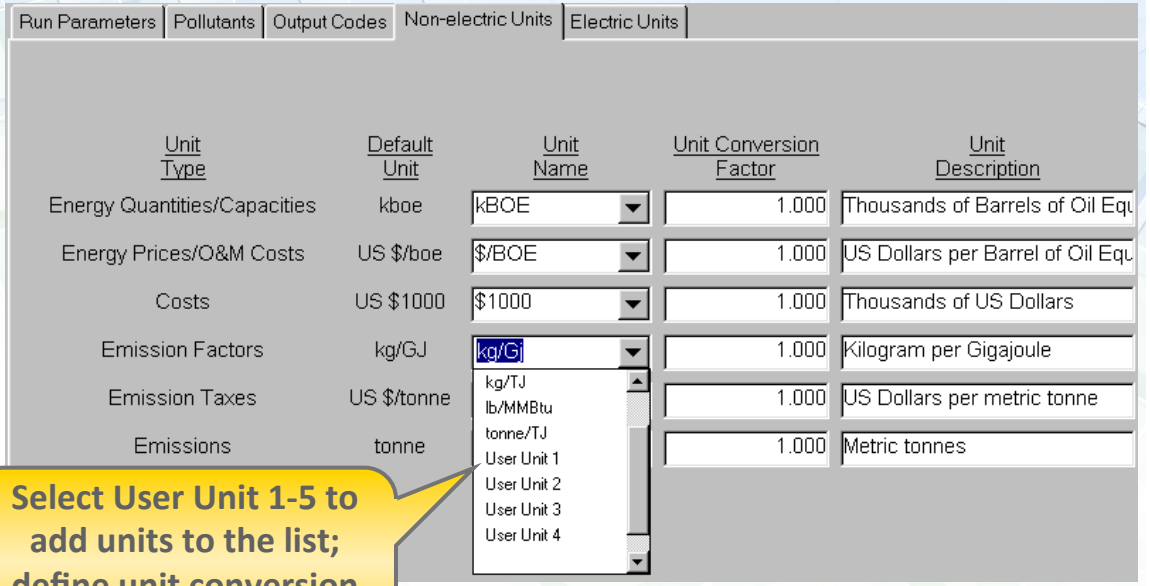
The User May Add or Delete Pollutants to the Current Default List



- ***Name*** indicates the name of the pollutant
- ***Abbreviation*** is the 5 character abbreviation for the pollutant
- ***Chemical Scale*** indicates whether the emissions are considered to be a linear function of a certain fuel characteristic, such as fuel carbon content for CO2 emissions, fuel sulfur content for SO2 emissions, etc.

The User May Specify the Units Used for Environmental Inputs and Outputs

- Environmental units may be specified for both non-electric and electric (if electric sector is used)
- ***Default Unit*** is the unit used internally by the model
- The pull-down menu under ***Unit Name*** provides a choice of alternative units
  - User may add units
  - User may delete units



- ***Unit Conversion Factor*** is used internally to convert the user-selected unit back to the default unit

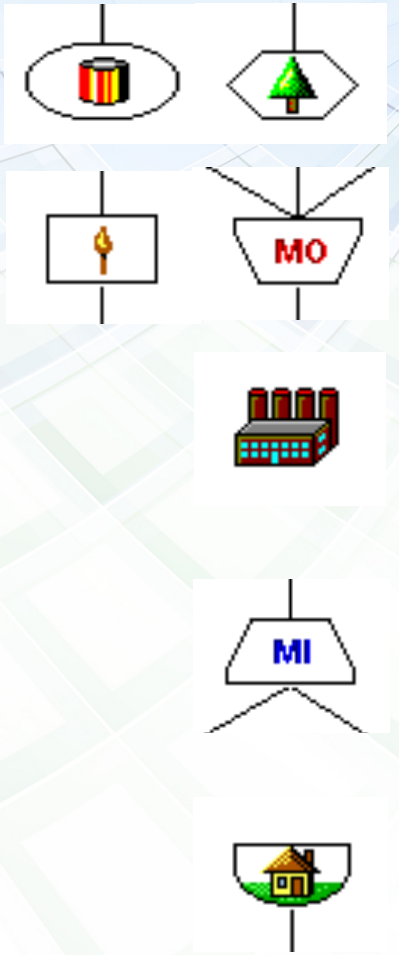
Default Unit = New Unit * Unit Conversion Factor

example: kg/GJ = kg/TJ * 0.001 TJ/GJ

- Note that the environmental units can only be selected if the "Perform Environmental Calculations" checkbox in Run Parameters is checked

Emissions Are Calculated and Reported by Node

- For depletable and renewable resources, emissions are calculated based on the resource output
- For single input/single output and multiple output processes, emissions are calculated based on process fuel/energy input
- For thermal electric generating units, emissions are calculated based on fuel input or fuel consumption
- For multiple input nodes, emissions are calculated based on process output
  - Output based emission factor needs to be calculated and input as weighted average across all fuel inputs
- For demand nodes, emissions are calculated based on process input
  - Demand nodes should only be used for situations where sectors are modeled in terms of final energy



Example: Emission Factors for Conversion Process

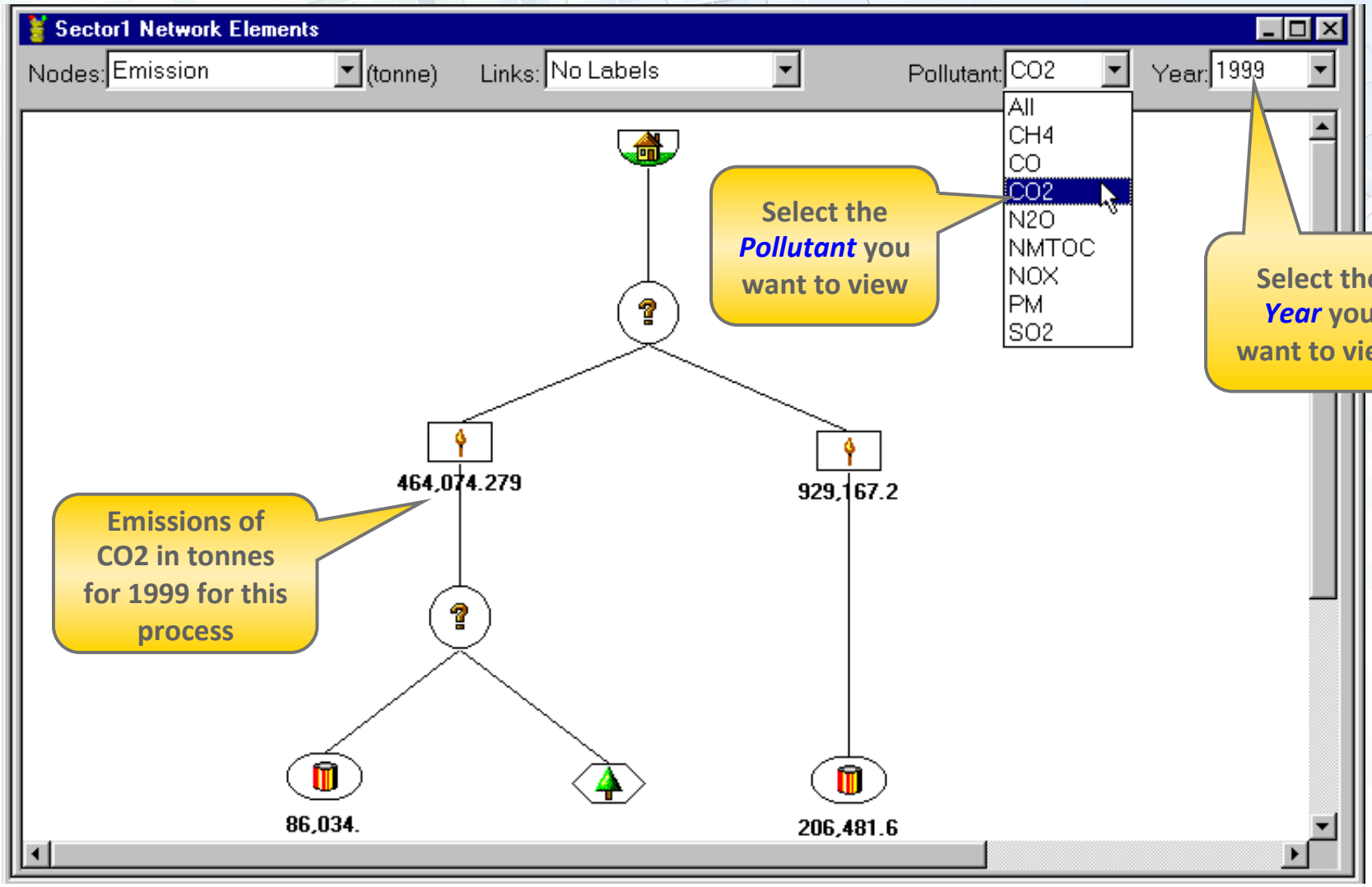
- ***Uncontrolled Emission Factor Input Based*** represents the emission factor for this specific process without using any pollution control technology; factor is based on the process input or fuel consumption
- ***Scale Value*** is the chemical content in percent that will be used to linearly scale the emissions
  - Scale value may be left blank if already included in emission factor (default 1.0)
  - For example CO2: enter 104.68 kg/GJ (1.349 * 77.6) and leave scale value blank; alternatively, enter 1.349 kg/GJ and 77.6% carbon
- ***Emissions Tax*** represents the tax imposed on a process for a specific pollutant
- All three parameters above can be changed year by year

Technical Properties | Economic Properties | **Emissions Properties** | Control Properties

Year	Pollutant Abbreviation	Uncontrolled Emission Factor Input Based (kg/Gj)	Chemical Scale	Scale Value (%)	Emissions Tax ($/tonne)
1999	CH4	0.001			
	CO2	1.349	Carbon	77.60	20.00
	N2O	0.002			
	NMTOC	0.001			
		0.399			
	PM	0.184	Ash	17.50	
	SO2	0.698	Sulfur	4.50	100.00

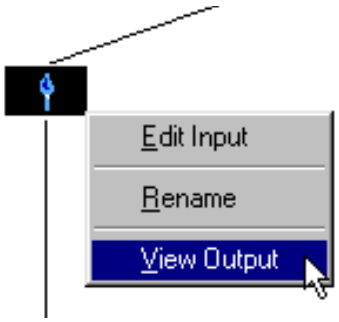
Chemical scale is defined in the *Run Parameters – Pollutants* screen

Environmental Results Can be Viewed Directly in the Network Using the Node Overlays



Environmental Reports and Graphs Can be Accessed for Each Node Using "View Output"

- Results can be viewed for each pollutant individually by using the ***Selected Pollutant*** pull-down menu or for all pollutants at the same time
- The pollutant selection in this screen will influence what will be displayed in the environmental graph screen



Energy Report | Energy Graph | Environmental Report | Environmental Graph

Year	Input Quantity (kBOE)	Pollutant Abbreviation	Emission Factor Times Scale Value (kg/Gj)	Emissions (tonne)	Emissions Taxes ($1000)
1999	1200	CO2	104.64515	720,243.281	14,404.866
2000	1245.777588	CO2	104.64515	747,719.114	14,954.382
2001	1292.328003	CO2	104.64515	775,658.800	15,513.176
2002	1340.535767	CO2	104.64515	804,593.232	16,091.865
2003	1389.497192	CO2	104.64515	833,980.013	16,679.600
2004	1439.415039	CO2	104.64515	863,940.841	17,278.817

Selected Pollutant: CO2

CH4
CO2
N2O
NMTOC
NOX

OK

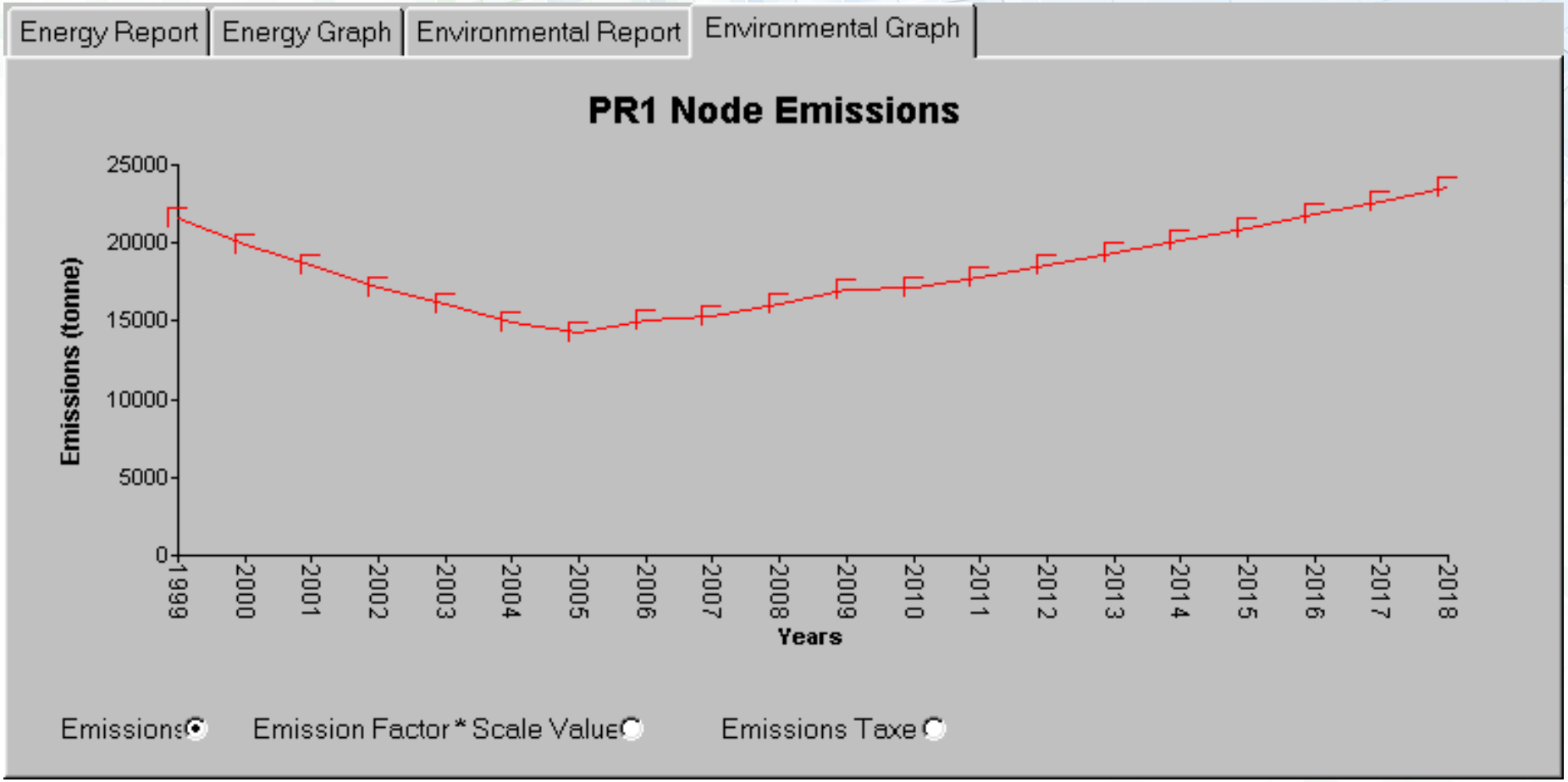
Select the pollutant you want to display in the report and in the graph

Environmental Reports and Graphs Can be Accessed for Each Node Using "View Output" (cont'd)

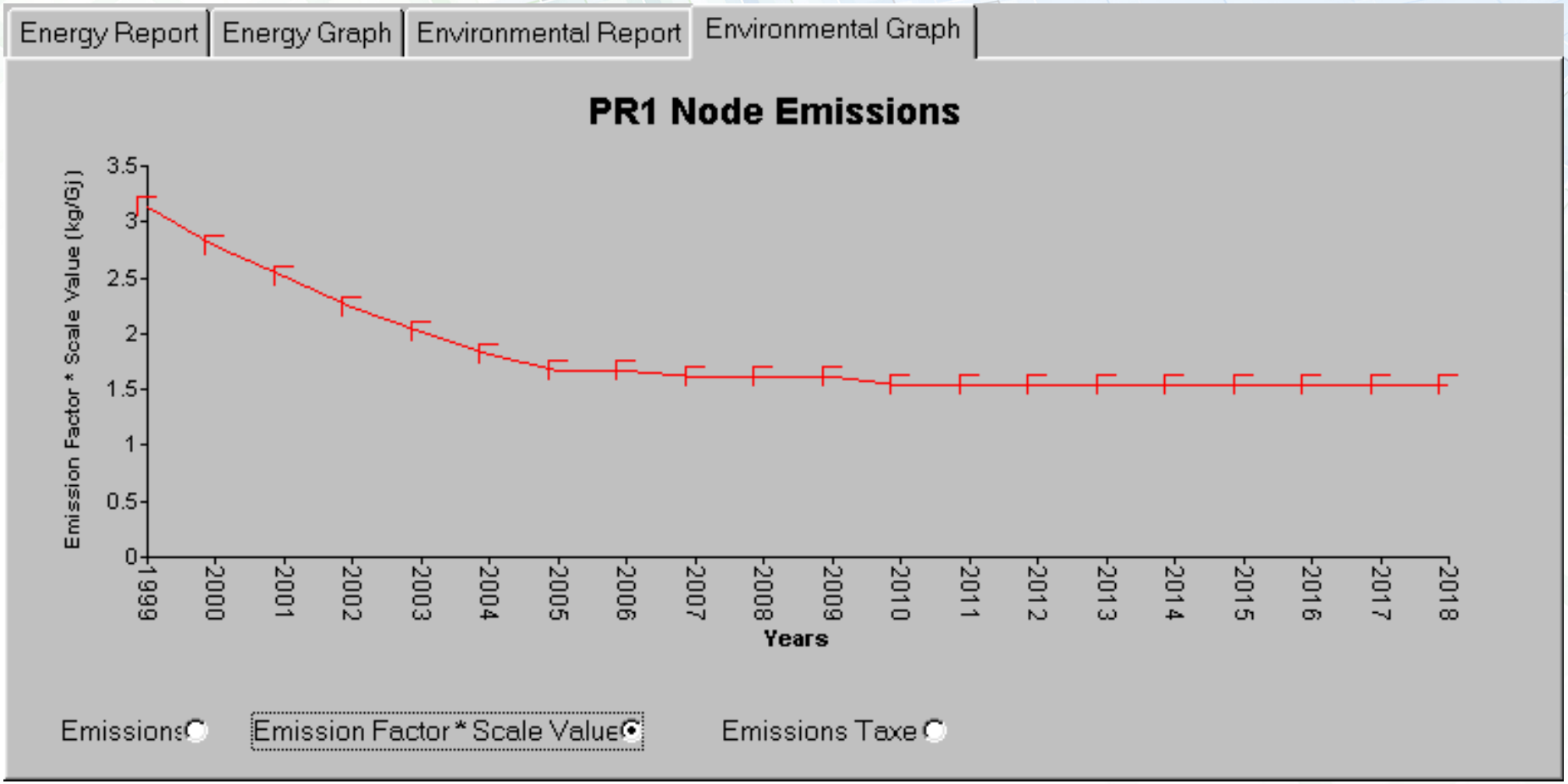
- ***Input Quantity*** reports the annual fuel consumption for this process
- ***Pollutant Abbreviation*** indicates which pollutant you are viewing
- ***Emission Factor Times Scale Value*** displays the combined or aggregate emission factor including the chemical scale for the selected pollutant
- ***Emissions*** reports the annual pollutant release for this process for the selected pollutant
- ***Emission Taxes*** displays the annual pollution taxes incurred by this process for this pollutant
  - There may be taxes on more than one pollutant
  - Taxes are calculated using the following equation

Annual Emission Tax	=	Annual Emissions	x	Emission Tax per tonne

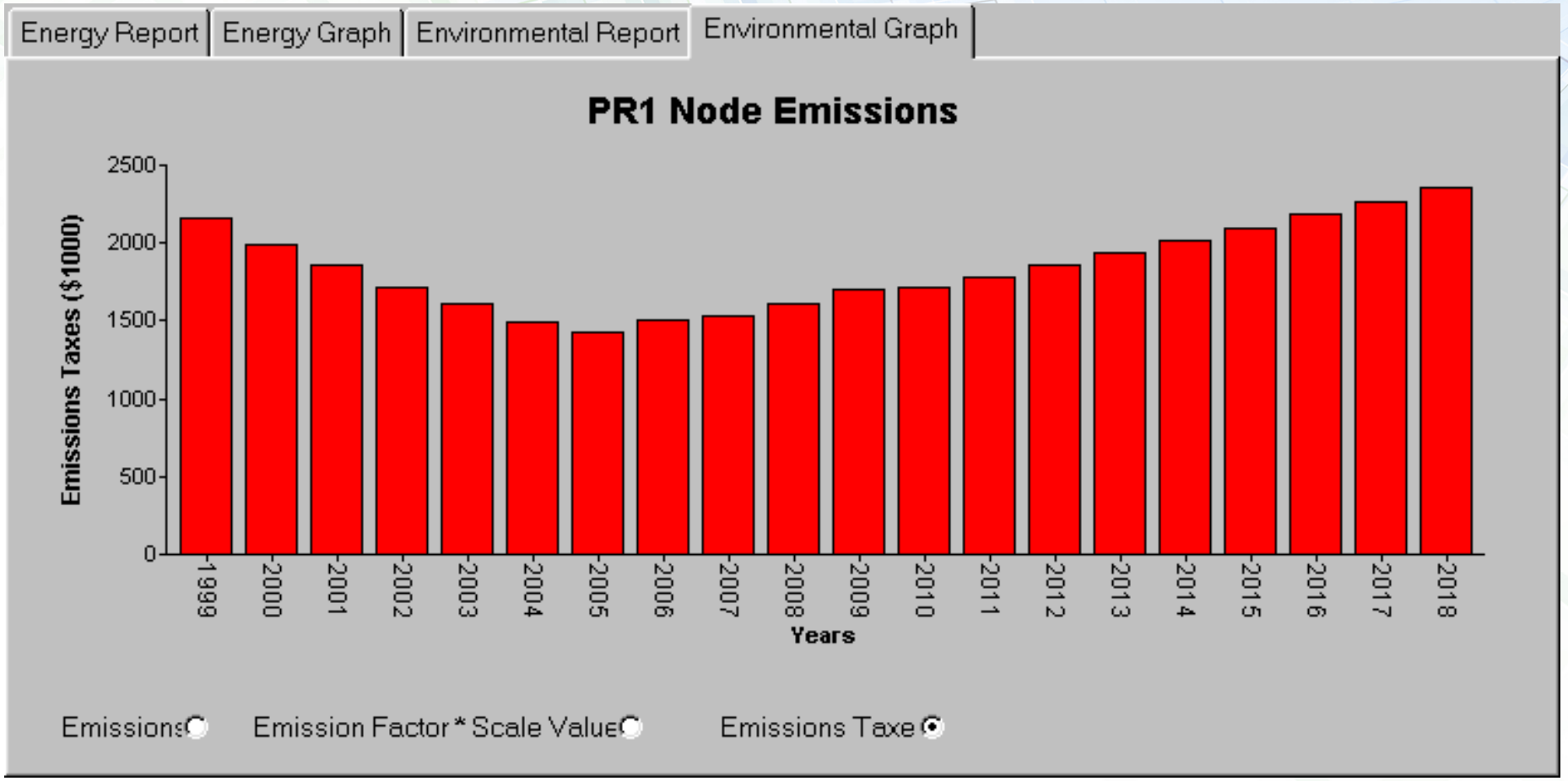
The Environmental Graph Shows Emission Results for the Pollutant(s) Selected in the Environmental Report



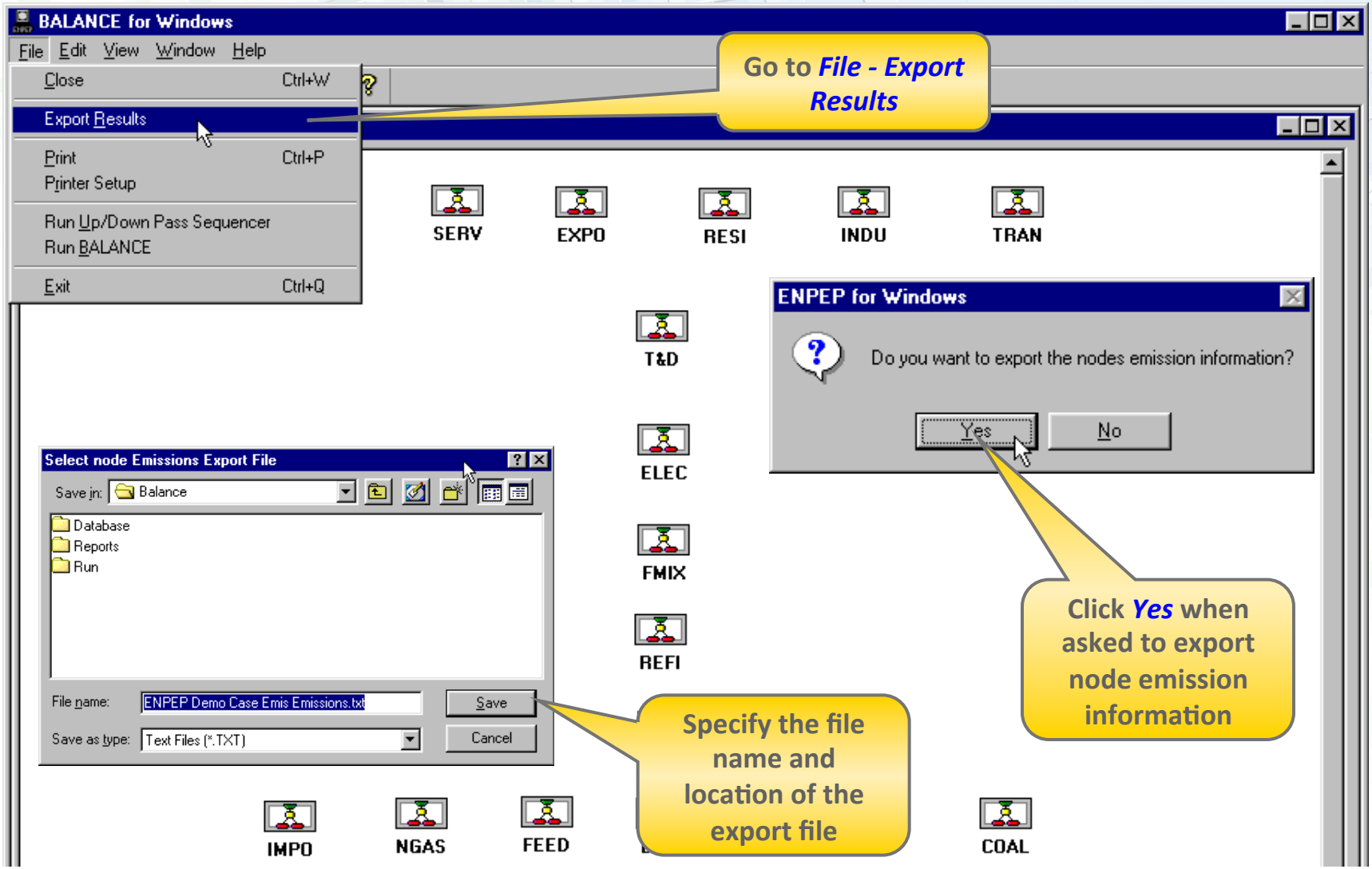
The Environmental Report Can Also be Used to View the Change in Emission Factor over Time



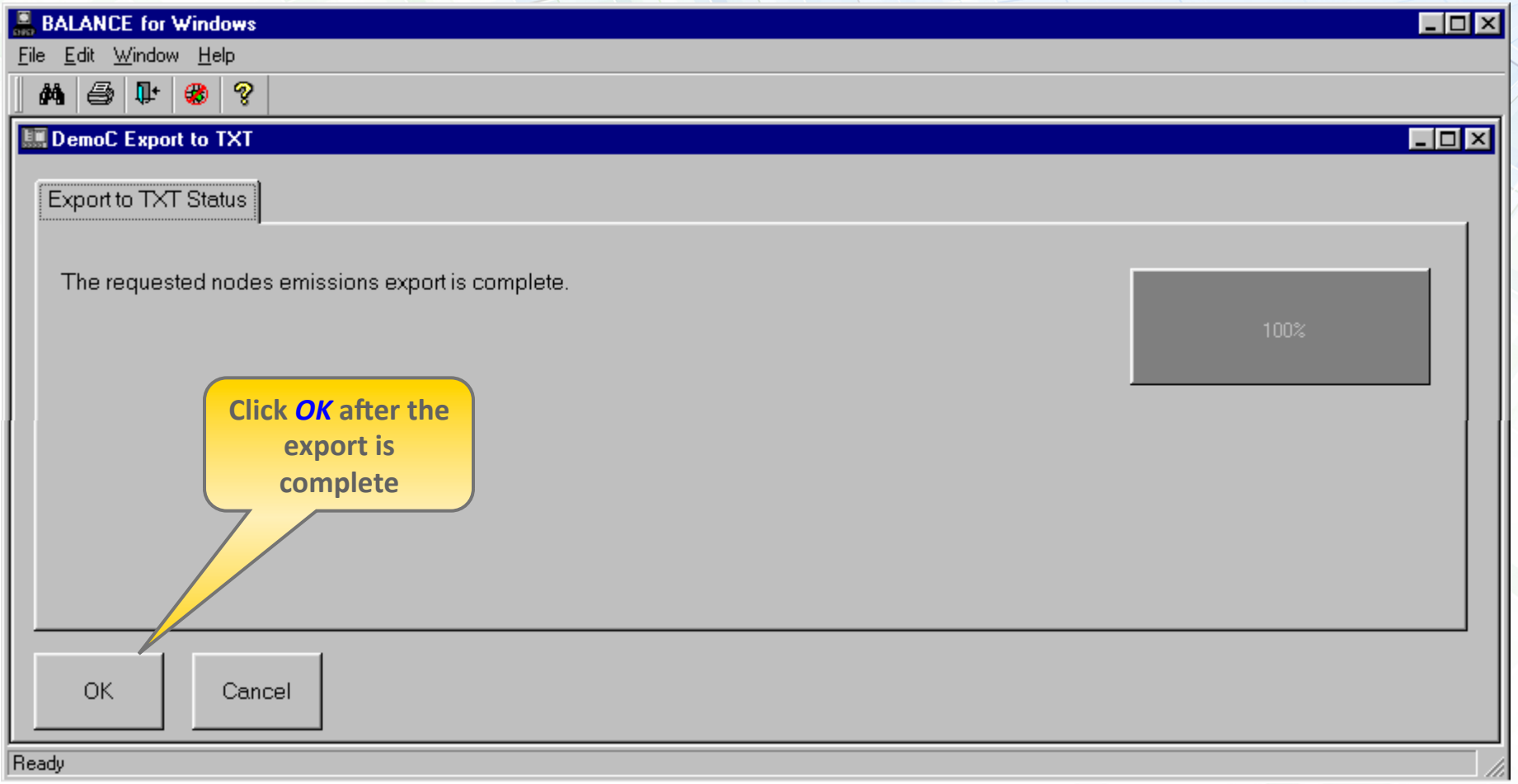
The Environmental Report Can be Used to Display the Annual Emissions Taxes Incurred by this Process



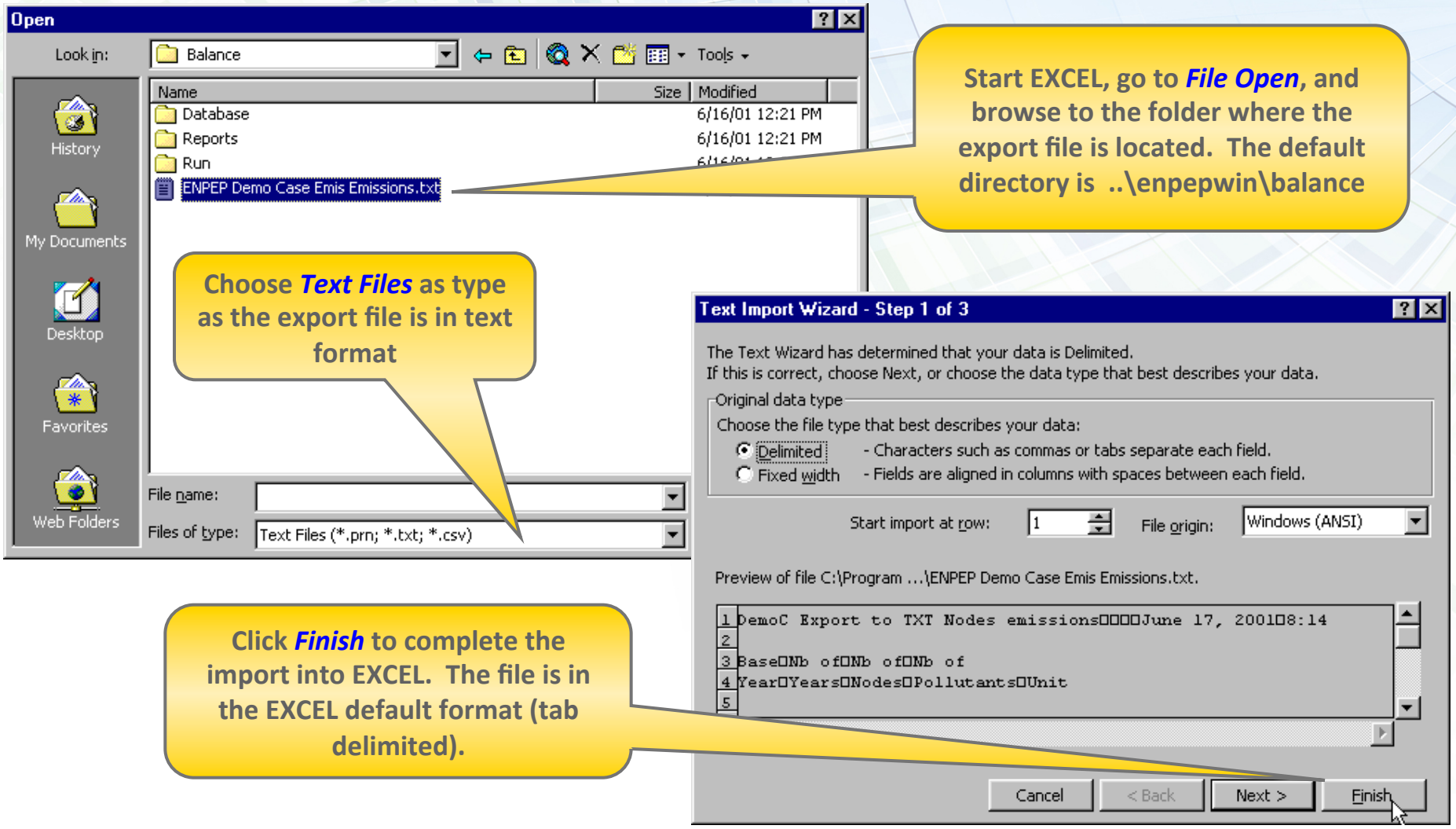
System-wide Emissions Results Can be Exported to EXCEL to Create Custom Reports and Graphs



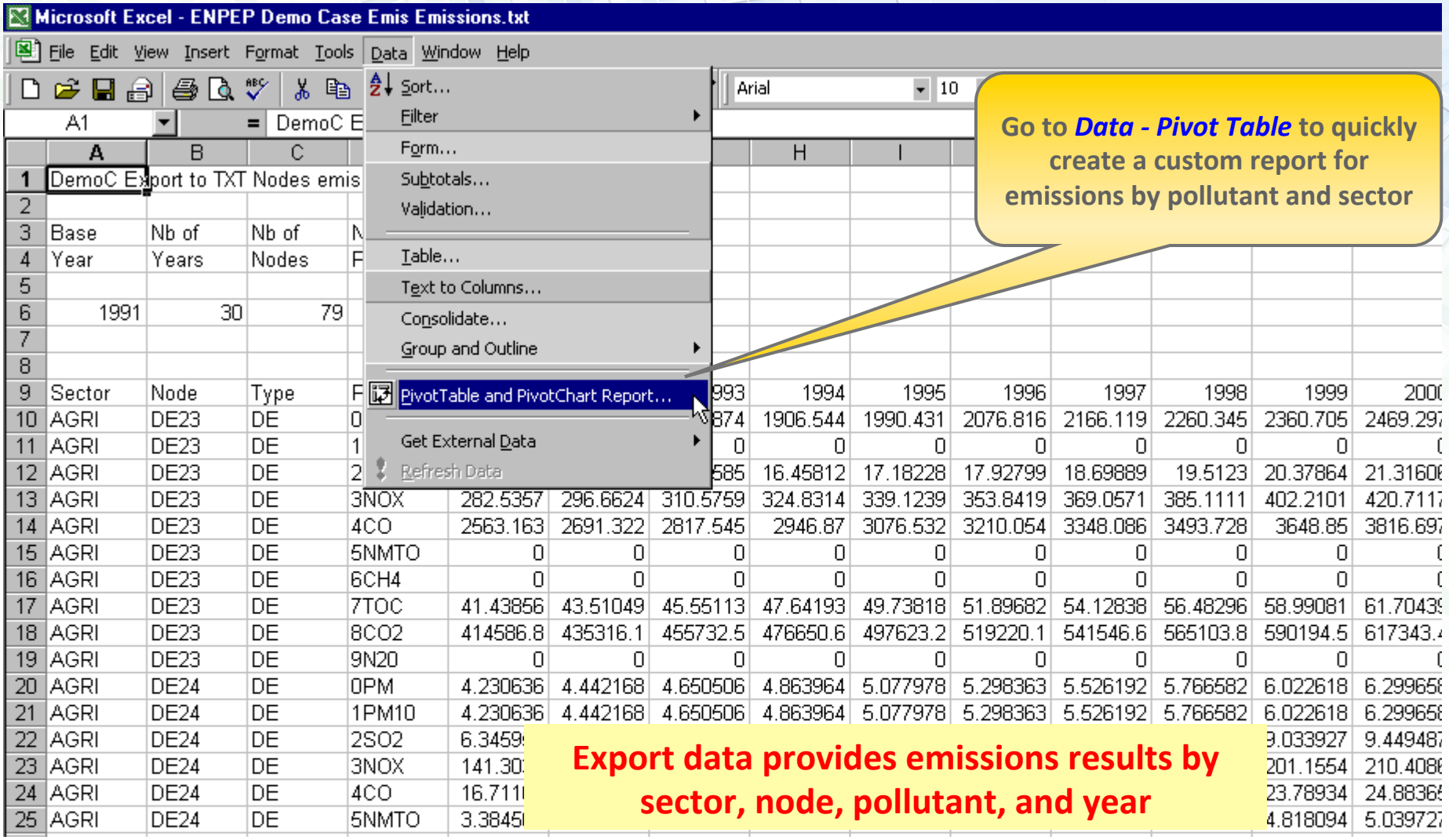
Exporting Emissions Results (cont'd)



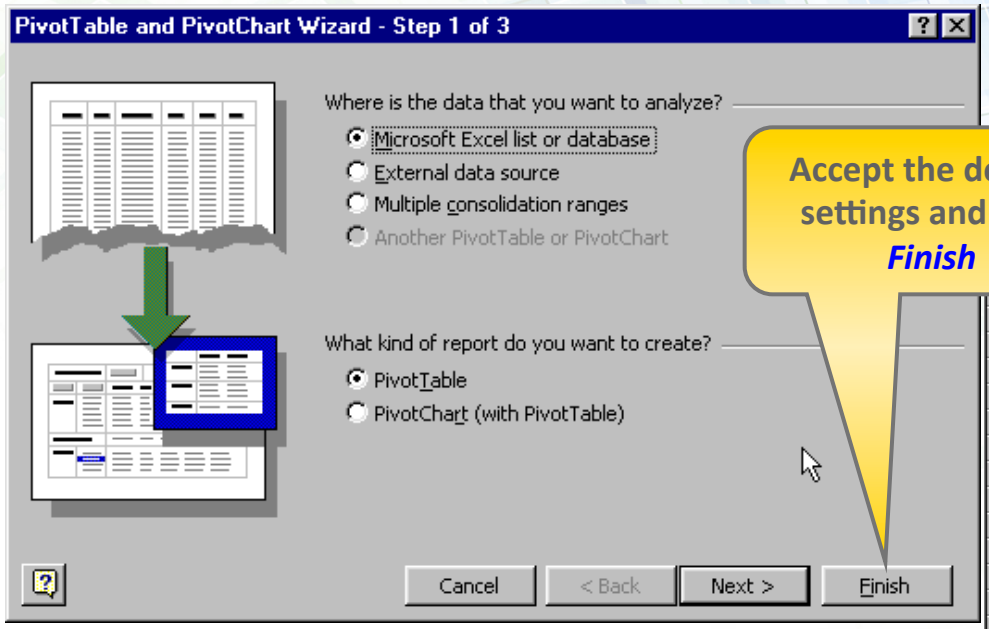
Exporting Emissions Results (cont'd)



Exporting Emissions Results (cont'd)



Exporting Emissions Results (cont'd)



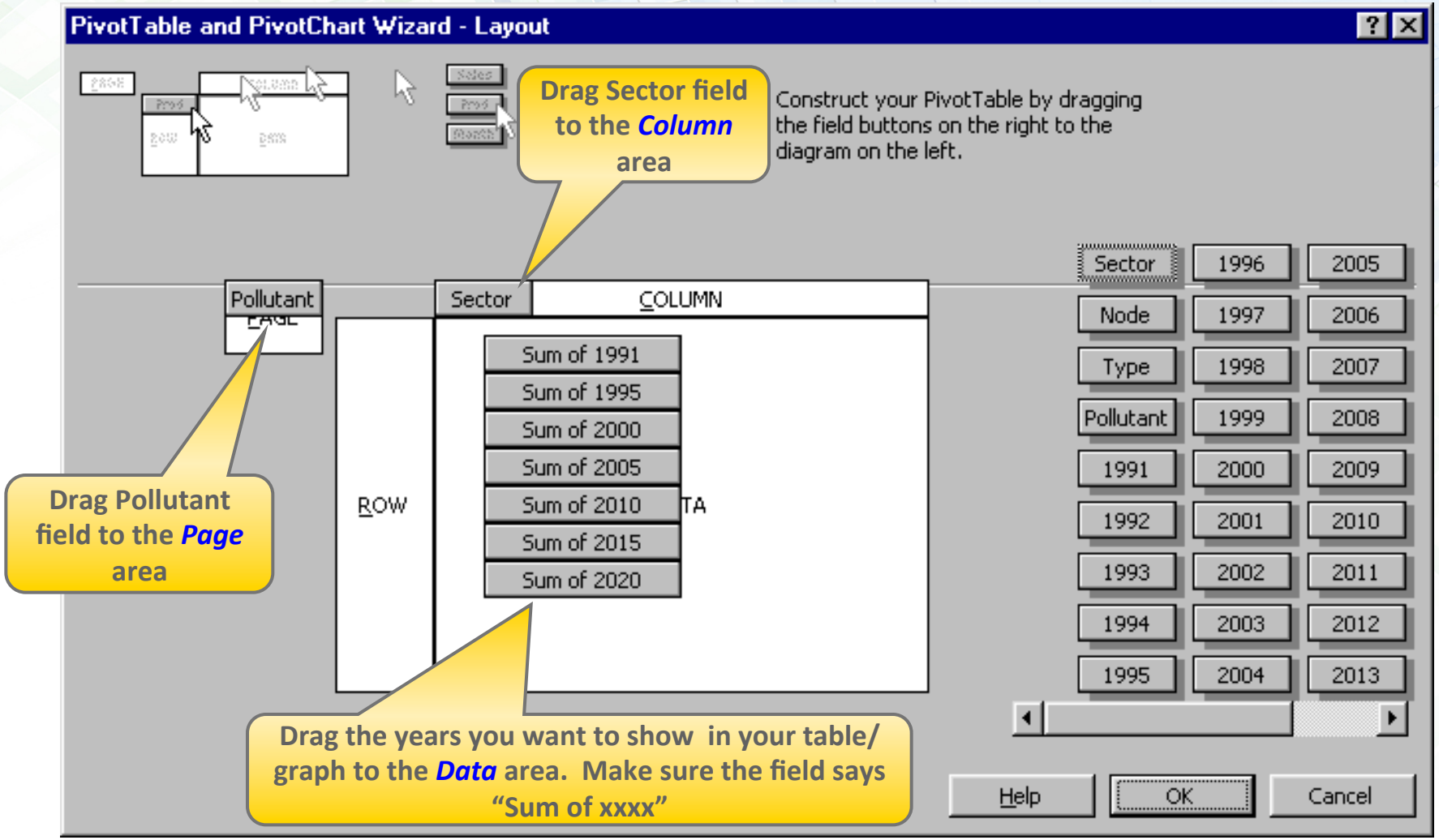
Accept the default settings and click ***Finish***

Select the data range that contains the header row and the data

	B	C	D	E	F	H	I
	port to TXT Nodes emissions			17-Jun-01			
3	Nb of	Nb of	Nb of				
4	Year	Years	Nodes	Pollutants	Unit		
5							
6	1991	30	79	10	tonne		
7							
8							
9	Sector	Node	Type	Pollutant	1991	1993	1994	1995
10	AGRI	DE23	DE	0PM	1658.296	1822.874	1906.544	1990.431
11	AGRI	DE23	DE	1PM10	0	0	0	0
12	AGRI						16.45812	17.18228
13	AGRI						324.8314	339.1239
14	AGRI	DE23	DE	4CO	2563.163	2817.545	2946.87	3076.532
15	AGRI	DE23	DE	5NMTO	0	0	0	0
16	AGRI	DE23	DE	6CH4	0	0	0	0
17	AGRI	DE23	DE	7TOC	41.43856	45.55113	47.64193	49.73818
18	AGRI	DE23	DE	8CO2	414586.8	455732.5	476650.6	497623.2
19	AGRI	DE23	DE	9N20	0	0	0	0
20	AGRI	DE24	DE	0PM	4.230636	4.650506	4.863964	5.077978
21	AGRI	DE24	DE	1PM10	4.230636	4.650506	4.863964	5.077978
22	AGRI	DE24	DE	2SO2	6.345954	6.975758	7.295946	7.616967
23	AGRI	DE24	DE	3NOX	141.3032	155.3269	162.4564	169.6045
24	AGRI	DE24	DE	4CO	16.71101	18.3695	19.21266	20.05801
25	AGRI	DE24	DE	5NMTO	3.384509	3.720405	3.891171	4.062383

Accept the default settings and click ***Finish***

Exporting Emissions Results (cont'd)



Exporting Emissions Results (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L
1		Pollutant	8CO2									
2												
3			Sector									
4		Data	AGRI	COAL	ELEC	FMIX	INDU	REFI	RESI	SERV	TRAN	Grand Total
5	1991	Sum of 1991	1,149,057	0	15,414,470	1,962	12,273,706	1,118,393	2,417,921	4,938,058	7,458,533	44,772,100
6	1995	Sum of 1995	1,379,198	0	24,450,304	0	13,592,133	1,307,607	2,563,915	6,003,888	8,951,511	58,248,557
7	2000	Sum of 2000	1,711,011	0	40,383,535	0	19,478,998	1,307,607	2,713,51			92,761
8	2005	Sum of 2005	2,189,336	0	57,088,782	0	26,005,222					08,693
9	2010	Sum of 2010	2,860,558	0	80,056,027	0	25,683,680	1,307,607	3,043,51			68,164
10	2015	Sum of 2015	2,860,558			0	24,528,976	1,307,607	2,796,72			28,459
11	2020	Sum of 2020				0	24,399,614	1,307,607	2,642,94			31,946

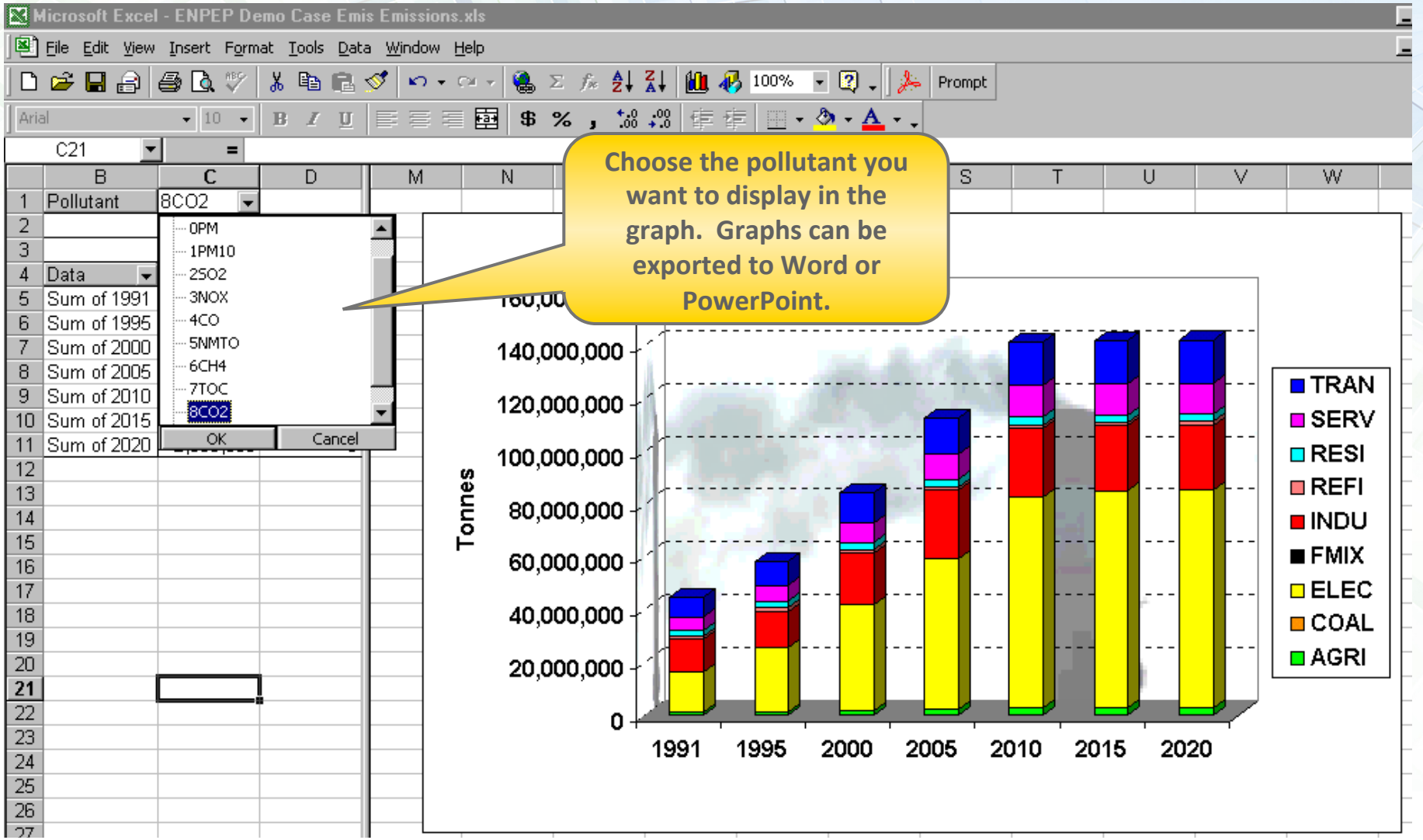
Insert column with years to use in the graph as x-axis values

Use formating commands to customize the pivot table report

	A	B	C	D	E	F	G	H	I	J	K	L
1		Pollutant	1PM10									
2			1PM10									
3			2SO2									
4		Data	3NOX									Grand Total
5	1991	Sum of 1991	4CO		348	1						97,700
6	1995	Sum of 1995	5NMTO		263	0	28,698					158,882
7	2000	Sum of 2000	6CH4		603	0	41,211					256,047
8	2005	Sum of 2005	7TOC		549	0	55,801					358,968
9	2010	Sum of 2010	8CO2		462	0	57,053	771	693	758	0	481,557
10	2015	Sum of 2015	9N20		370	0	54,719	771	660	758	0	491,098
11	2020	Sum of 2020	OK	Cancel	932	0	54,373	771	637	758	0	493,290
12												

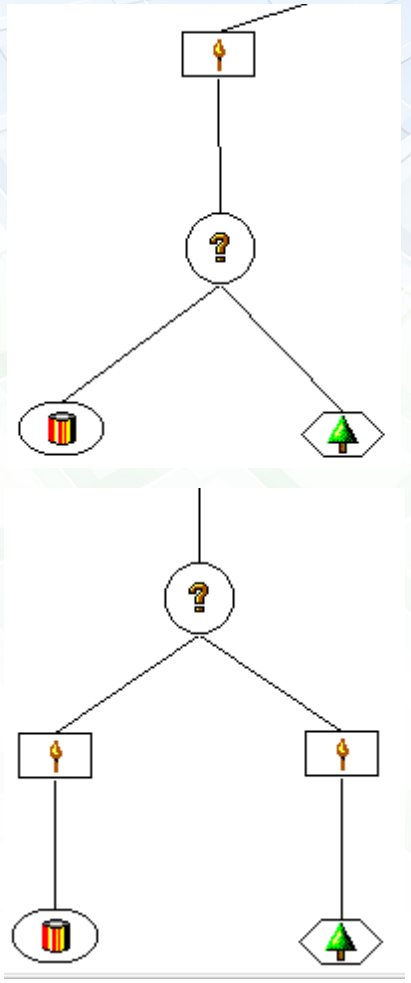
Select the pollutant you want to view. Table and graph automatically gets updated

Exporting Emissions Results (cont'd)



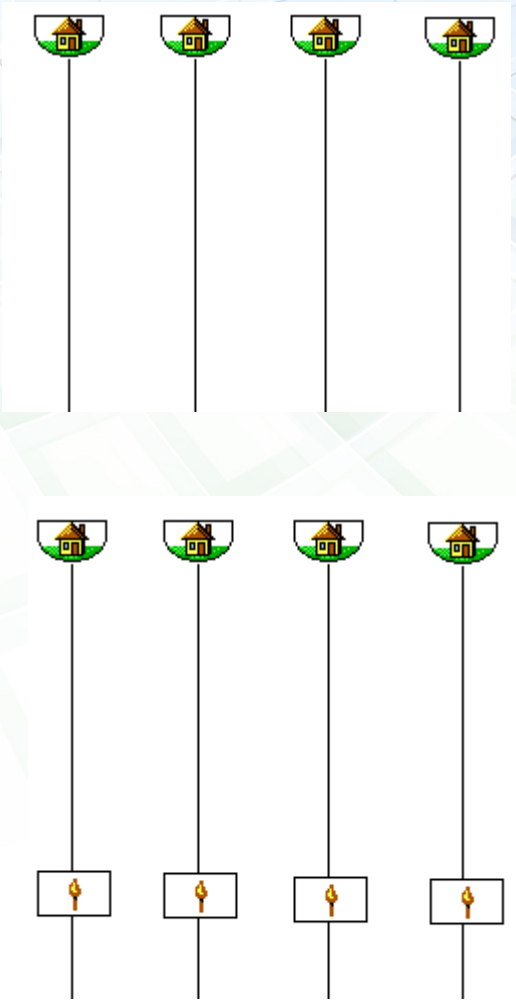
Some Modeling Issues

- If your process is using a mix of fuels that changes every year (e.g., oil and gas), your average emission factor also changes every year
- The fuel mix, and thus the average emission factor may be different in each scenario
- The current version of the model does not track this information
- User needs to ensure consistency
- One way to do this is to compute an average emission factor year-by-year and enter the values into the model (this may have to be done for each of your scenarios)
- A better way to do this is by modifying the network structure
- The modified structure would make sure that each process uses just one type of fuel

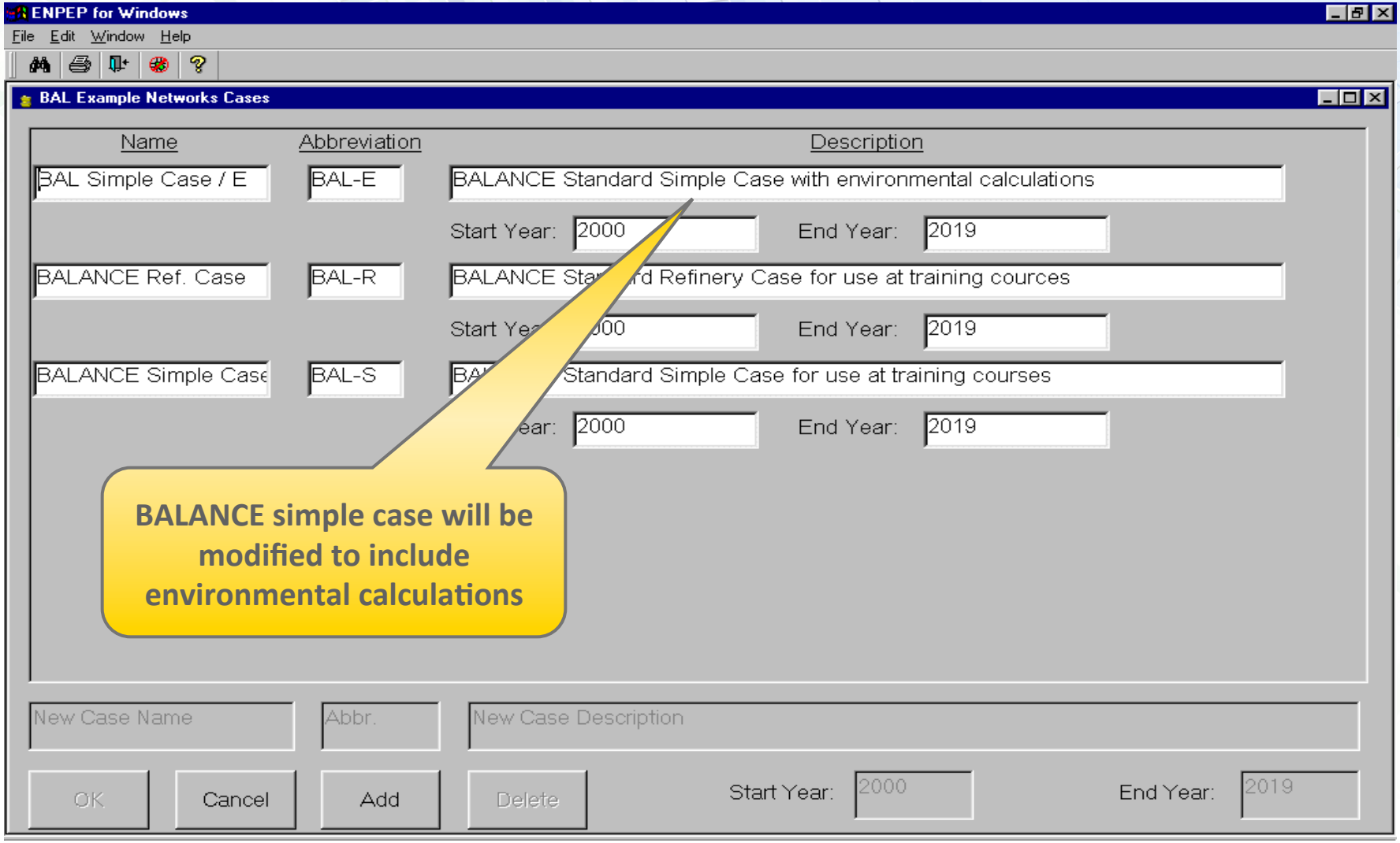


Some Modeling Issues (cont'd)

- If your end use sectors are mostly in final energy structure without any conversion processes, emissions will not be accounted for
- One way to deal with this is to include emission factors into the demand nodes
  - If demand nodes are projecting a mix of fuels, the emission factors need to account for this by using a weighted average based on the mix ratio
  - When converting the sector into useful energy demand by inserting conversion processes, the emission factors in the demand nodes must be deleted
- Another way to deal with this is to include so-called "dummy" processes
  - Single input/single outputs
  - Efficiency 1.0, no cost, no change in energy flows
  - Only to obtain emissions for sectors with final energy



Example: Simple Network with Emissions



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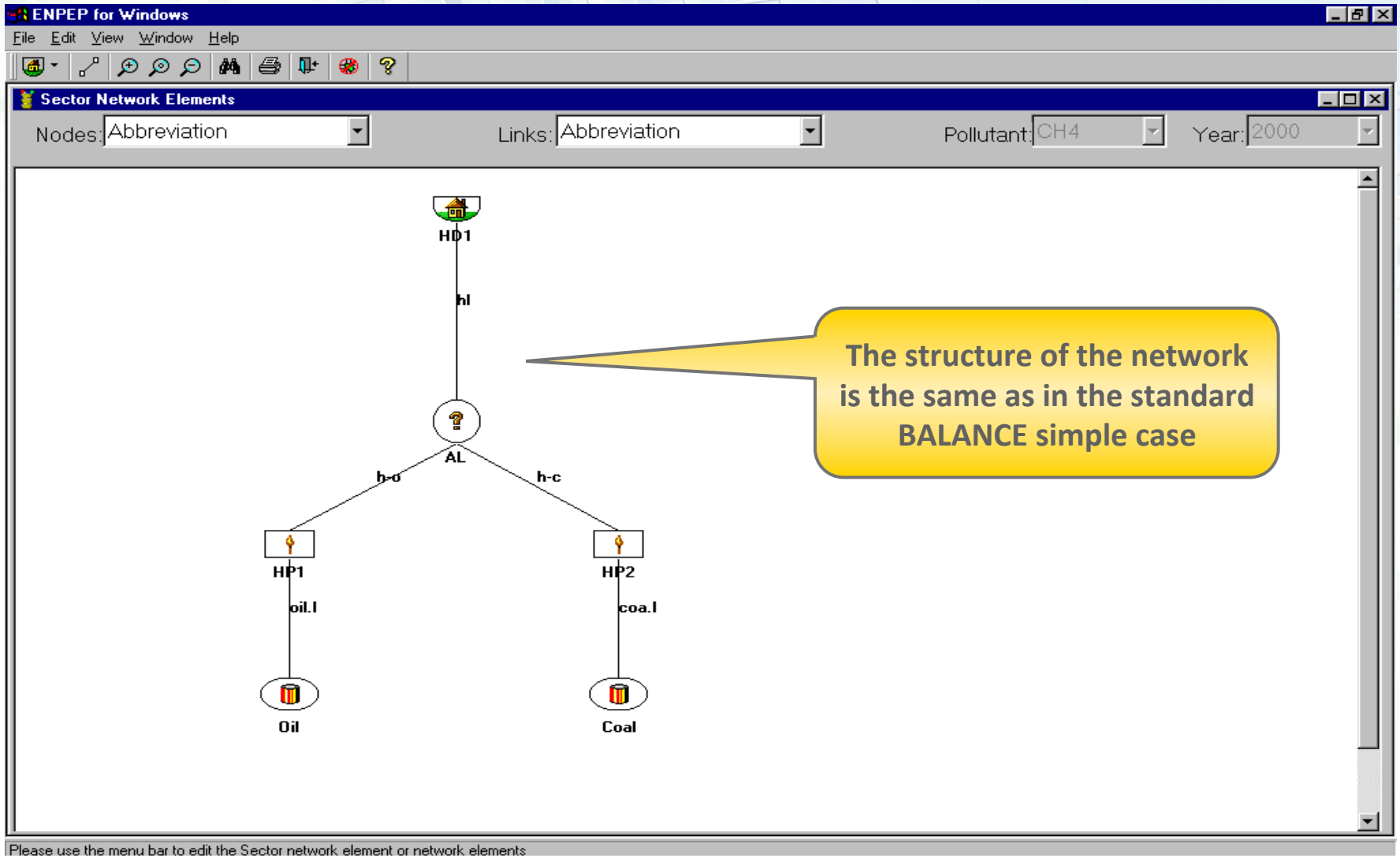

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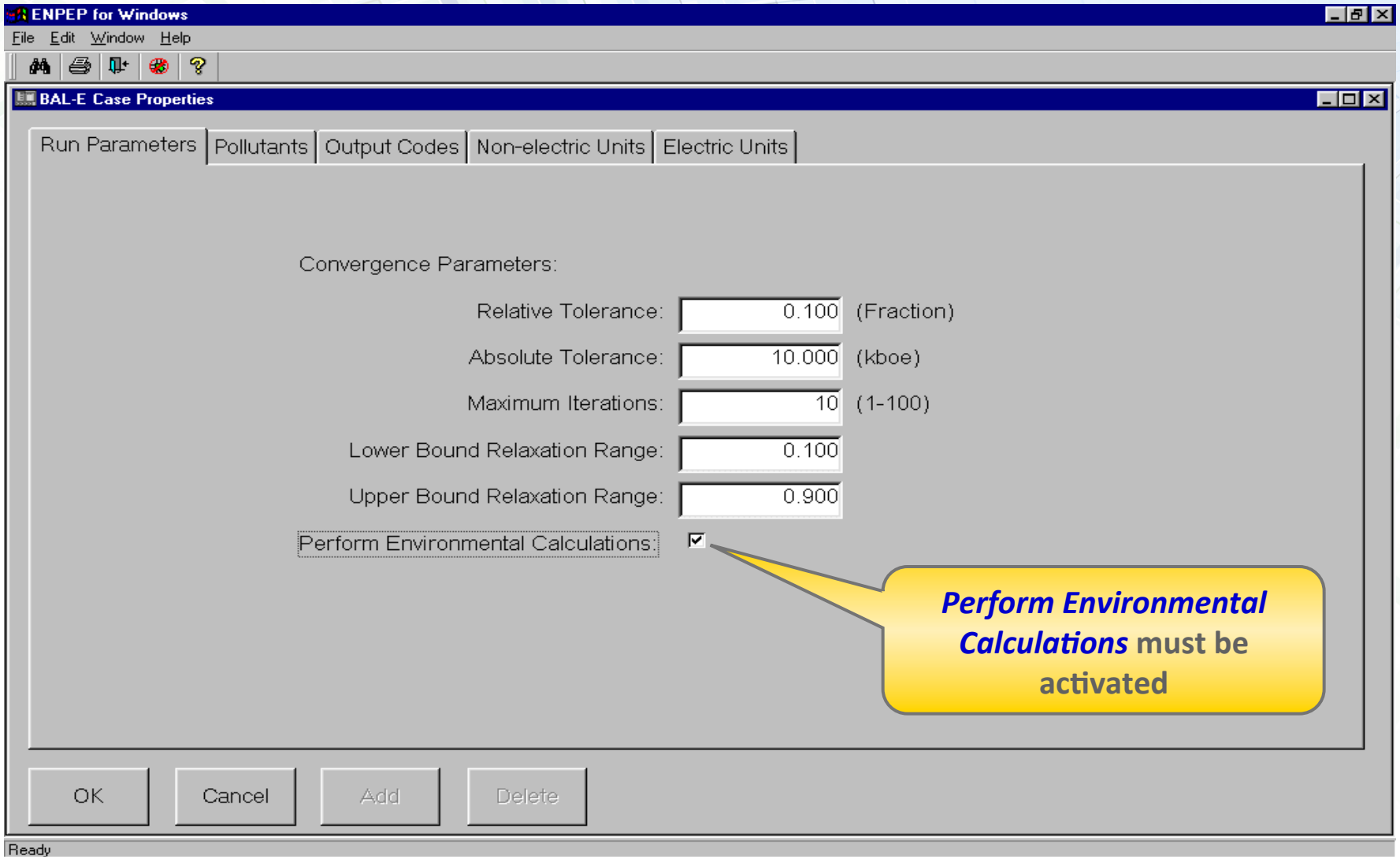

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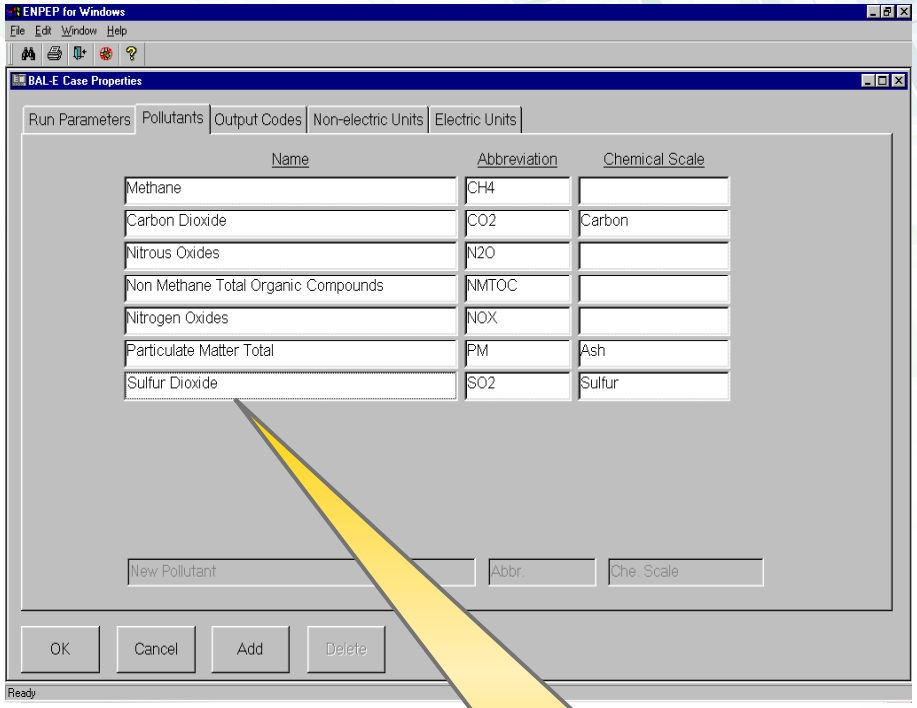
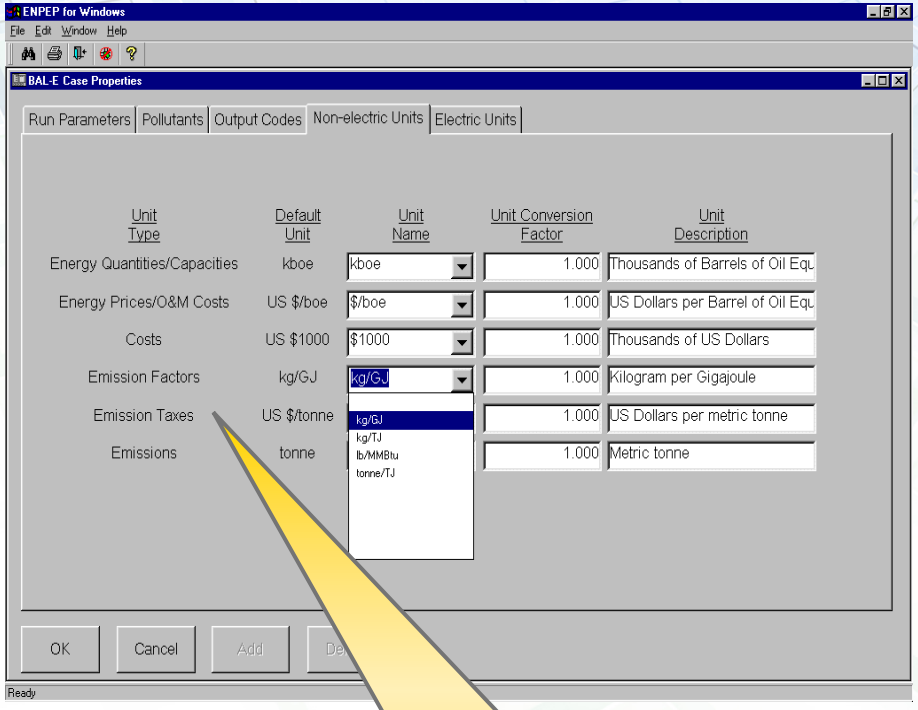
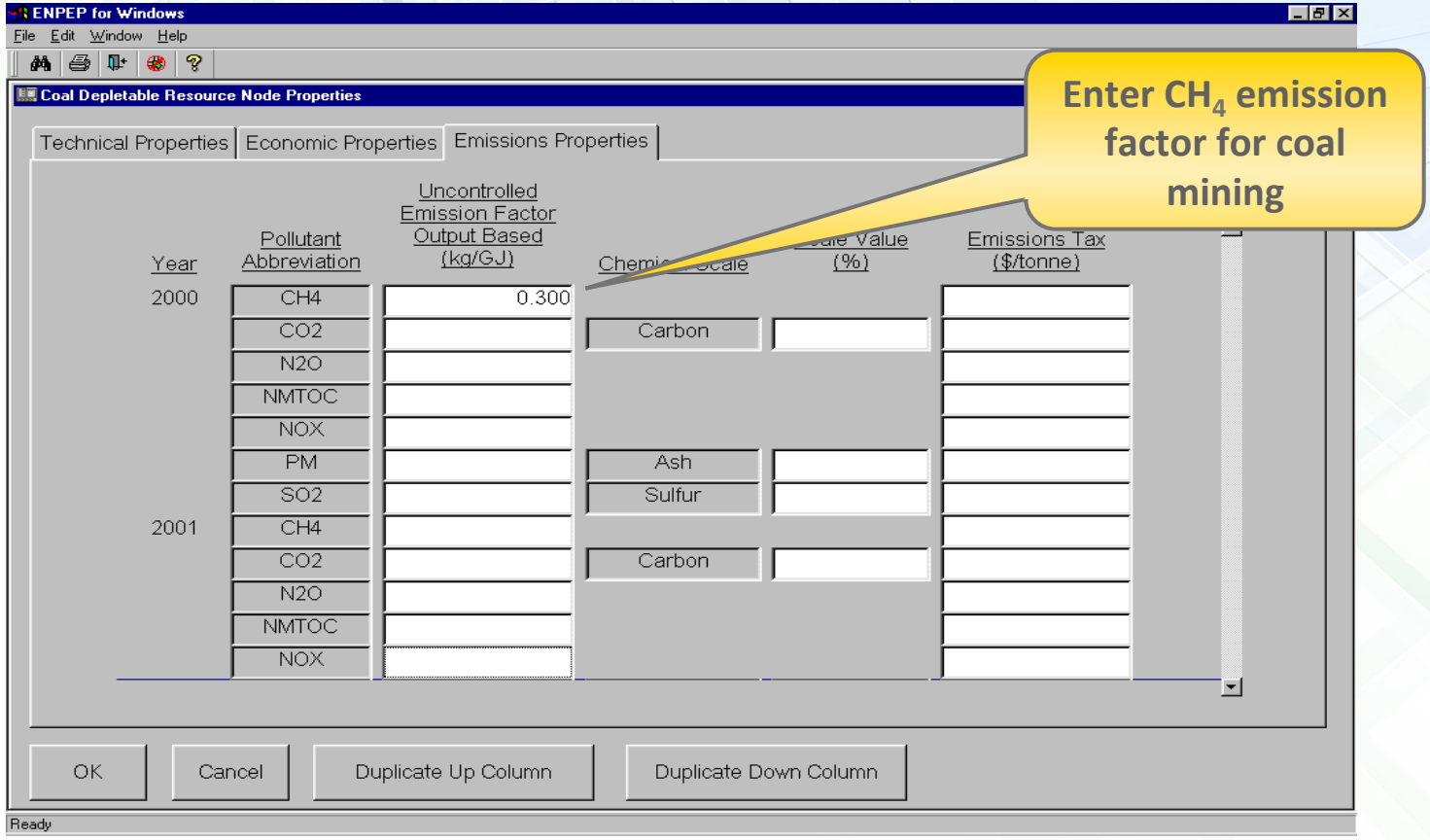




Check the list of pollutants and modify if necessary

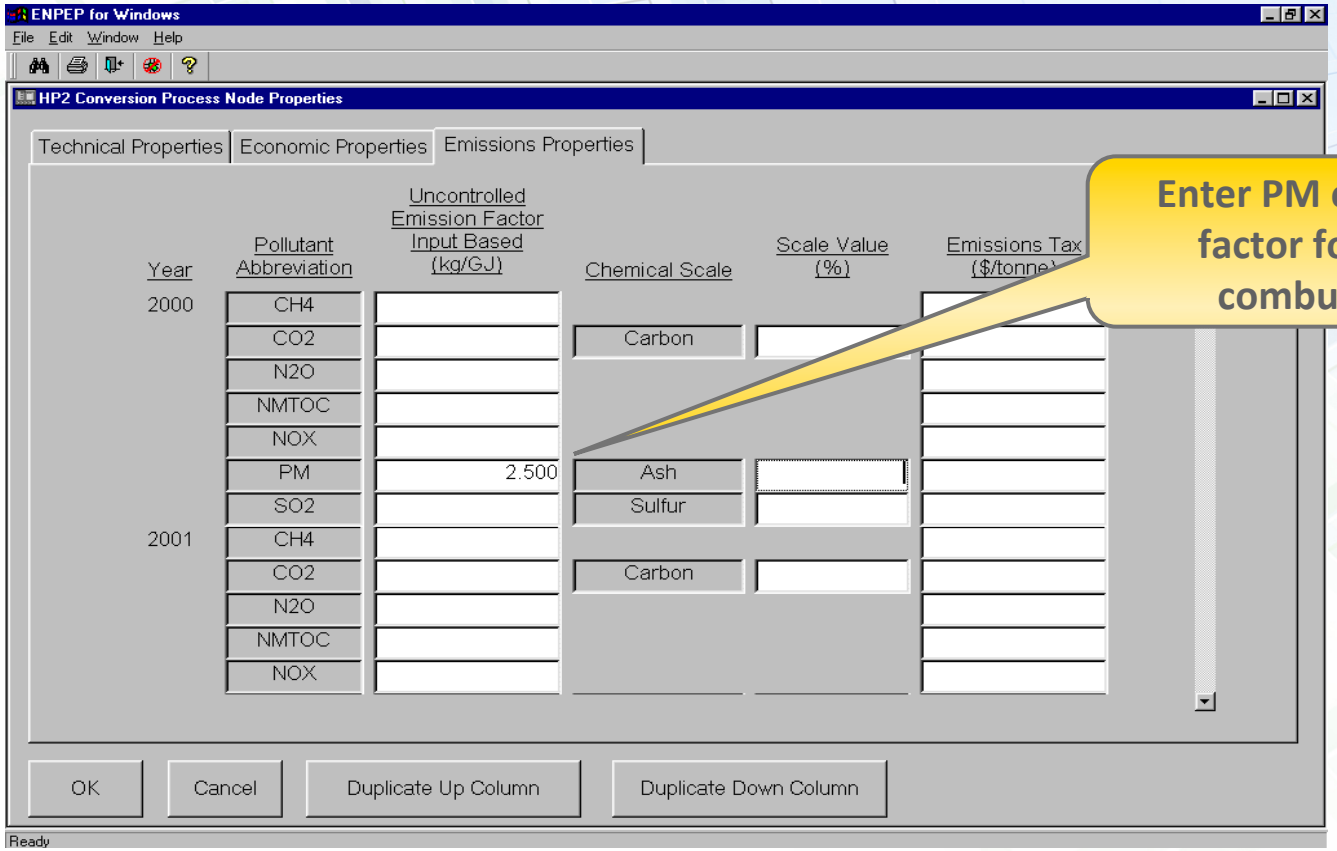
Check the emission factor and emissions units and modify if necessary

Example: Simple Network with Uncontrolled Emissions



COAL MINING: methane (CH_4) emissions = 10 m^3/tonne of coal (range 0.3-24) = = 0.5 m^3/GJ (1 tonne of coal = 20 GJ) = 0.3 kg CH_4/GJ (1 m^3 CH_4 = 0.6 kg)

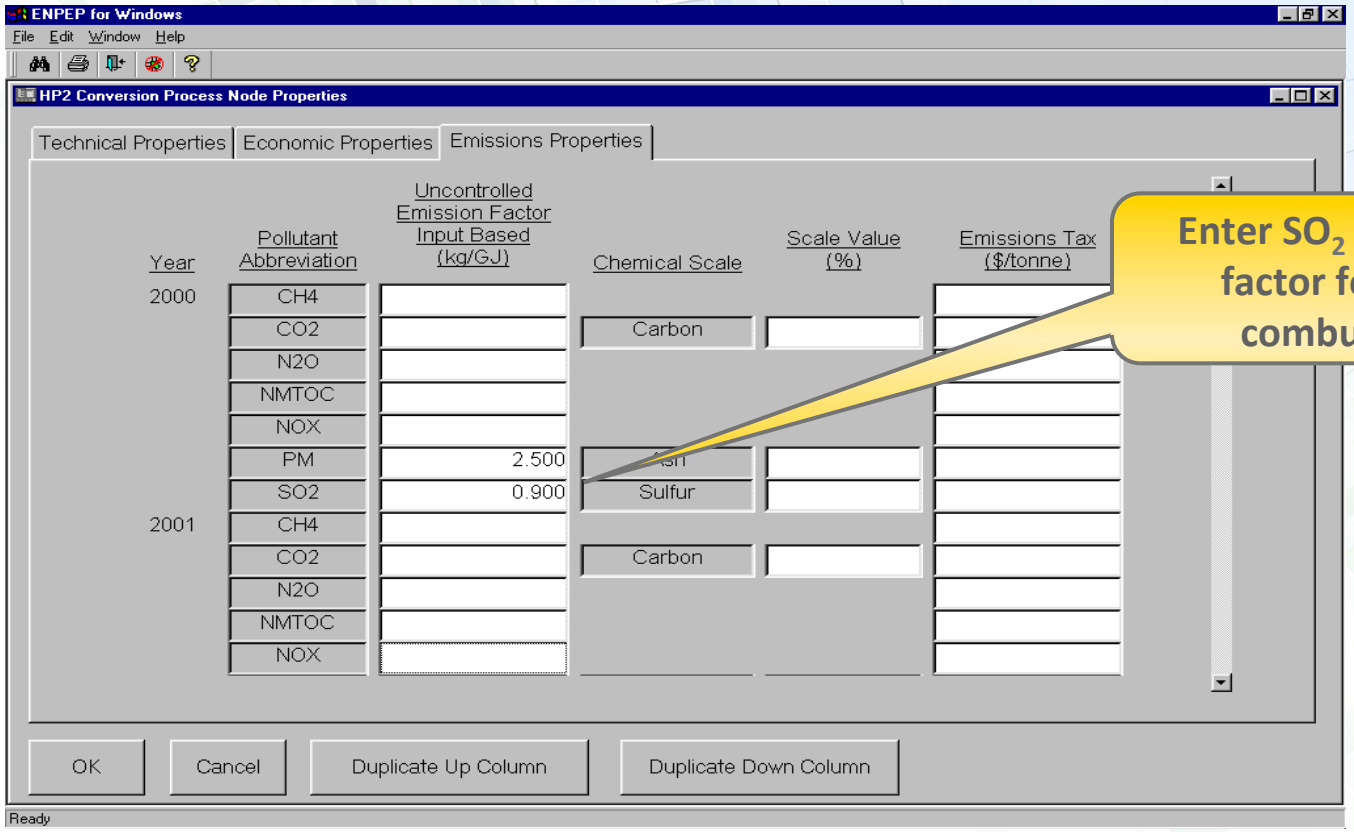
Example: Simple Network with Uncontrolled Emissions



COAL COMBUSTION (PM): 1 kg coal with 10% ash = 0.1 kg ash generated = 0.05 kg bottom ash + 0.05 kg fly ash => 0.05 kg fly ash / kg coal = 50 kg/tonne

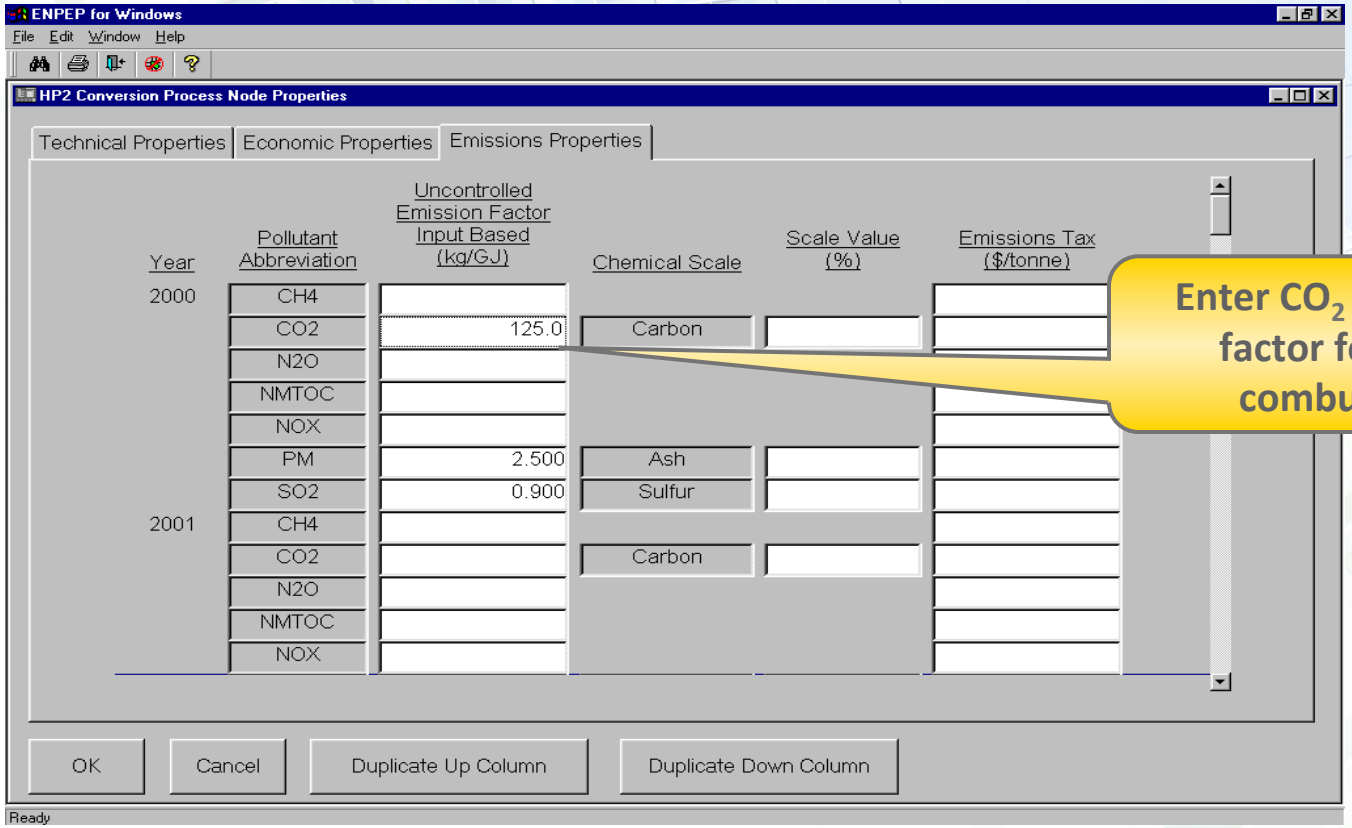
= 2.5 kg PM/GJ (1 tonne of coal = 20 GJ) - uncontrolled emissions

Example: Simple Network with Uncontrolled Emissions



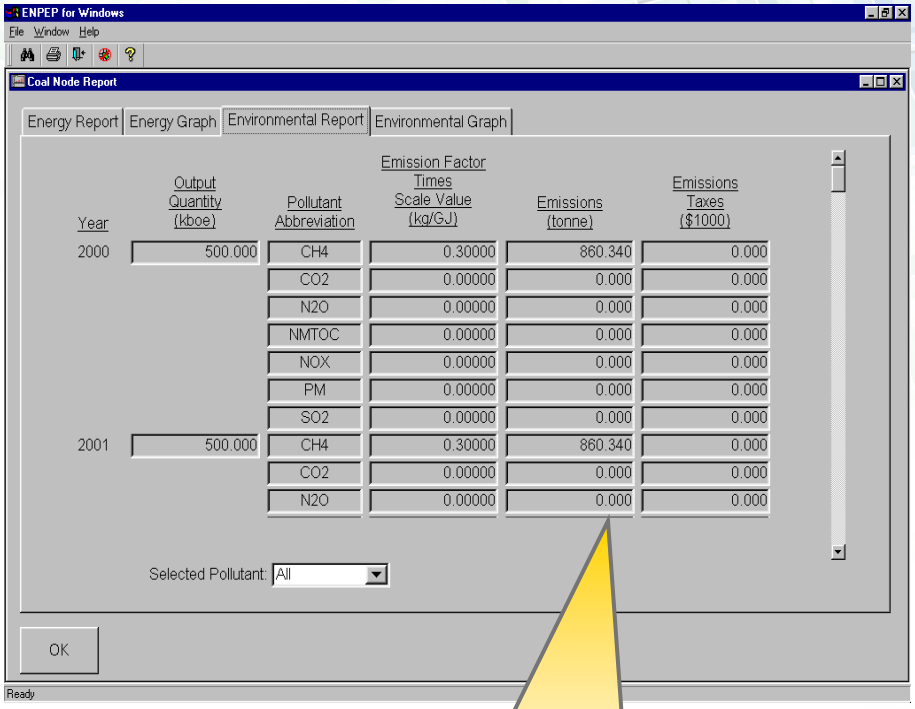
COAL COMBUSTION (SO_2): 1 kg coal with 1% sulfur = 0.01 kg S generated = 0.02 kg SO_2 (molar ratio SO_2/S = 64/32 = 2.0) generated = 0.018 kg emitted (90% oxidization) => 0.018 kg SO_2 / kg coal = 18 kg/tonne = 0.9 kg SO_2/GJ (1 tonne of coal = 20 GJ) - uncontrolled emissions

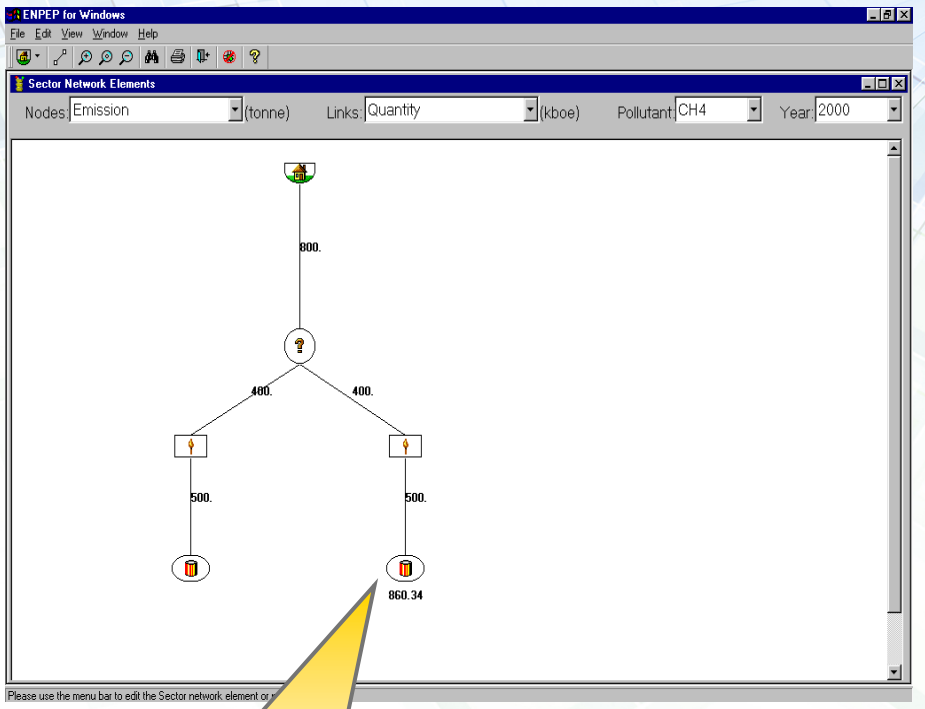
Example: Simple Network with Uncontrolled Emissions



COAL COMBUSTION (CO_2): 1 kg coal with 70% C = 0.7 kg C generated = 2.5 kg CO_2 (molar ratio CO_2/C = 44/12 = 3.664) generated = 2.5 kg emitted (100% oxidization) => 2.5 kg CO_2 / kg coal = 2500 kg/tonne = 125 kg CO_2/GJ (1 tonne of coal = 20 GJ) - uncontrolled emissions

Example: Simple Network with Uncontrolled Emissions

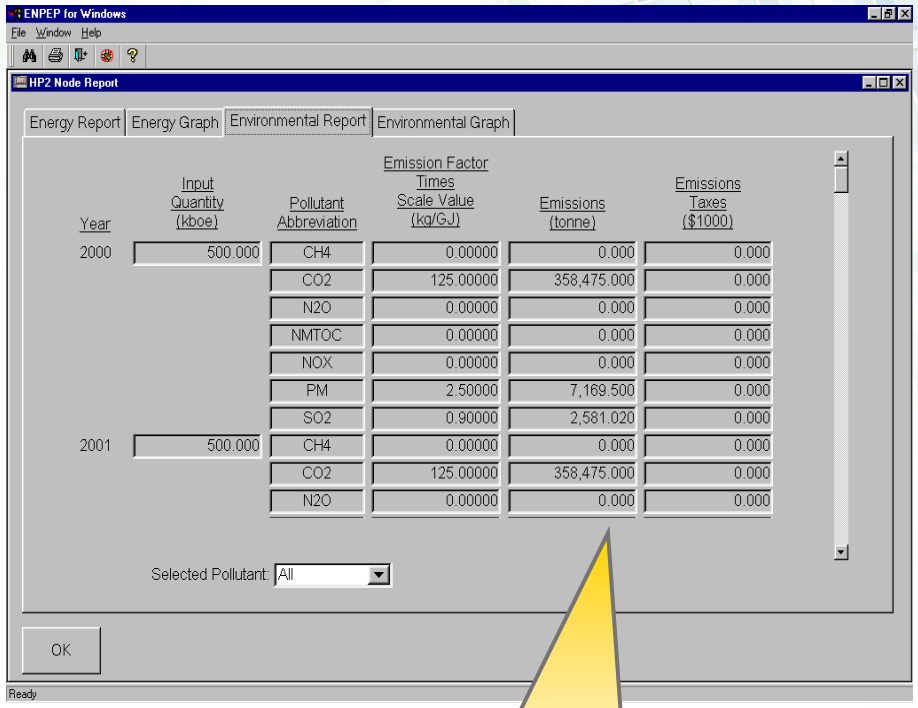


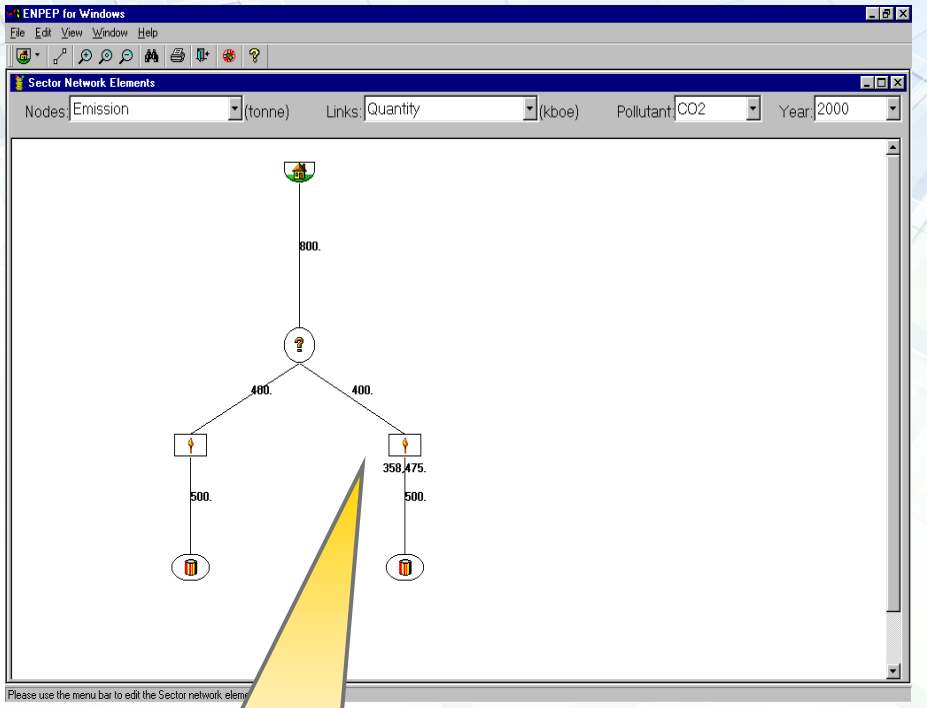


Results for coal mine: environmental report/ graph

Results for coal mine: environmental network info

Example: Simple Network with Uncontrolled Emissions





Results for coal boiler: environmental report/ graph

Results for coal boiler: environmental network info

Example: Simple Network with Controlled Emissions

- Please note that the current version of ENPEP-BALANCE does not explicitly include emissions control technologies
  - This feature may be introduced in future versions

- To model controlled emissions (e.g., for PM, SO2, NOX) with the current version
  - Recalculate the emission factors based on the uncontrolled emission factor and the average control efficiency as below
  - Enter the controlled emission factor into the uncontrolled emission factor field
  - If available, emission control costs can be added to the conversion process or plant economic properties
  - Rerun the case

Controlled Emission Factor	**=**	**Uncontrolled Emission Factor**	**x**	**(1- Control Efficiency/100)**

- It may be advisable to keep 2 separate cases: one case with uncontrolled emission and one case with controlled emissions

Example: Simple Network with Controlled Emissions

- PM emissions from coal combustion
  - Uncontrolled emission factor: 2.5 kg PM/GJ
  - Abatement technology with 98% efficiency
  - Controlled emission factor: 2.5 x (1 - 0.98) = 0.05 kg PM/GJ

- SO2 emissions from coal combustion
  - Uncontrolled emission factor: 0.9 kg SO2/GJ
  - Abatement technology with 80% efficiency
  - Controlled emission factor: 0.9 x (1 - 0.8) = 0.18 kg SO2/GJ

- CO2 emissions from coal combustion
  - Uncontrolled emission factor: 125 kg CO2/GJ
  - No abatement technology available

Example: Simple Network with Controlled Emissions