Chapter 4
Energy from Fossil Fuels: Digital Mapping of Sources and Environmental Issues

At present fossil fuels are the most important sources of energy. In many countries most of the energy is still generated by nonrenewable sources, which are represented by a limited reserve coal, oil, and gas. They will become scarce and therefore prohibitively expensive after a few decades. The choice can be limited by other criteria such as air pollution and climate change. The pollution due to coal power stations depends on the quality of the coal. A coal power station can emit each year a few million tonnes of carbon dioxide, a million tonnes of ash, half a million tonnes of gypsum, and other pollutants such as nitrous oxide, sulfur dioxide, and smaller amounts of other toxic wastes. Besides that coal mining is dangerous, dirty and many miners contract debilitating diseases such as silicosis. Oil became one of the world's leading energy sources. It has a higher caloric value than coal and is more easily transported. Transport and industry are more dependent on oil supply than on the availability of coal. Moreover oil is the basis of petrochemical industries such as plastics, drugs, and paints. Similarly to coal, main oil reserves last for a few decades, and then the production becomes increasingly expensive. The changes can be more rapid in individual countries, which do not have their own oilfields. Since a large fraction of the oil is used for transport, it is imperative to discover new ways of driving cars and ships. The energy supply of gas has risen rapidly. As the rate of consumption is rising, it is unlikely to last longer than oil. In comparison with other fossil fuels, gas is now the cheapest and convenient energy source, but its world's reserve is severely limited.

4.1 Description of Fossil Fuels

Fossil fuels are the residues of dead organic matter, particularly vegetation, trapped for millions of years in sedimentary deposits. Coal forms from geological processes, which involve the burying of plants under anaerobic conditions in swamps. Initially, it becomes peat and is overlain gradually by rock, raising the pressure and

L. Matejicek, *Assessment of Energy Sources Using GIS*,
DOI 10.1007/978-3-319-52694-2_4

temperature of the organic matter. Oil results from more dispersed organic matter, such as organic sediments on a continental shelf that are buried by geological processes and subjected to a high-pressure cooking deep underground. It can migrate through cracks and form large underground pools. Nongaseous fossil fuels are made up of complicated molecules with backbones of many carbon atoms, which originate from the residues of their plant parents: mostly the light atoms of carbon, hydrogen, sulfur, and phosphorus that constitute carbohydrates. Over the long period, the oxygen content is reduced, and the dominate molecular form becomes a mixture of hydrocarbons. But there is a significant variability in the atomic and molecular composition of these fuels in dependence on geologic deposits in different regions of the Earth's surface. Natural gas is composed on the fewest molecular components, low-molecular-weight hydrocarbons.

The energy role of fossil fuels is in their fuel heating value, which is the amount of heat released during the combustion. The heating value is a characteristic for each fuel and is usually measured in units of energy per unit of mass (kJ/kg, kJ/mol, kcal/kg, or Btu/lb). The heat of combustion for fuels can be expressed as the higher heating value (HHV) or lower heating value (LHV). The HHV is determined by bringing all the products of combustion back to the original pre-combustion temperature and in particular condensing any vapor produced. The LHV is determined by subtracting the heat of vaporization of the water vapor from the HHV. For many fuels, the higher heating value is correct, which is particularly relevant for natural gas, whose high hydrogen content produces much water, when it is burned in condensing boilers and power plants with flue-gas condensation. For the applications, which waste heat by producing unused water vapor, the lower heating value must be used to give a real estimate for the process. The difference between HHV and LHV depends on the chemical composition of the fuel. A relation between HHV to LHV can be expressed by

$$HHV = LHV + H_{\mathrm{v}} \frac{n_{\mathrm{H_2O},out}}{n_{fuel,in}} \tag{4.1}$$

where H_{v} is the heat of vaporization of water and $n_{\mathrm{H^2O,out}}$ and $n_{\mathrm{fuel,in}}$ are the number of moles of water vaporized and fuel combusted, respectively.

Commercially available fossil fuels include coal (anthracite and bituminous, subbituminous, and lignite), liquid petroleum (gasoline, diesel fuel, kerosene, heating fuels), and petroleum gases (natural gas, ethane, propane, butane). The heating values of these fossil fuels are highly variable in dependence on molecular composition and inert components. Besides varied structure of the fossil fuels, the distinction between HHV and LHV is primarily a matter of convention. Sellers like to quote their price in terms of dollars per energy units of HHV, which is a lower price than that per energy units of LHV. On the other hand, producers of energy such as power plants or heating plants prefer to rate their plant efficiency in terms of electrical or heating energy produced per energy unit of LHV, which shows a higher efficiency in comparison with HHV. The heat values (LHV) of selected fuels together with percentage of carbon and carbon dioxide are shown in Table 4.1.

Table 4.1 Heat values of various fuels

Fuel	LHV (MJ/kg)	% Carbon	CO_2 (g/MJ)
Hydrogen	121	0	0
Petrol/gasoline	44–46		
Diesel fuel	45		
Crude oil	42–44	89	70–73
Methanol	20	37	
Liquefied petroleum gas (LPG)	49	81	59
Natural gas (UK, United States, Australia)	38–39	76	51
Natural gas (Canada)	37		
Natural gas (Russia)	34		
Natural gas as LNG (Australia)	55		
Hard black coal (IEA definition)	>23.9		
Hard black coal (Australia and Canada)	c 25.5	67	90
Subbituminous coal (IEA definition)	17.4–23.9		
Subbituminous coal (Australia and Canada)	c 18		
Lignite/brown coal (IEA definition)	<17.4		
Lignite/brown coal (Australia, electricity)	c 10	25	1.25 (kg/kWh)
Firewood (dry)	16	42	94
Natural uranium, in LWR (normal reactor)	500 (GJ/kg)	0	0
Natural uranium, in LWR with U and Pu recycle	650 (GJ/kg)	0	0

Source: World Nuclear Association, 2010
Notes: % carbon is by mass; mass CO_2 = 3.667 mass C; one tonne of oil equivalent (toe) is equal to 41.868 GJ

4.1.1 Coal as an Energy Source

Coal as a variety of solid organic fuels refers to a wide range of sedimentary rock materials spanning a continuous quality scale for combustion. This continuous series is used to be divided into two main categories such as hard coal and brown coal. Hard coal contains two subcategories such as anthracite and bituminous coal (coking coal and other bituminous coal). Also brown coal contains two subcategories that is subbituminous coal and lignite. But coal categories vary in the classification system in dependence on national and international specifications such as caloric value, volatile matter content, fixed carbon content, and other criteria. Fuel combustion and emissions are also affected by the degree of dilution by moisture and ash and contamination by sulfur and other trace elements. Thus the International Coal Classification of the Economic Commission for Europe (UNECE) recognizes two broad categories, which are determined by a gross caloric value that accounts for water in the exhaust leaving as vapor, and includes liquid water in the fuel prior to combustion and basic composition. The category hard coal is characterized as coal of gross calorific value not less than 5700 kcal/kg (23.9 GJ/t) on an ash-free but moist basis and with a mean random reflectance of vitrinite of at least 0.6.

Fig. 4.1 Coal surface mine with mining equipment such as excavators and conveyors

The category brown coal is non-agglomerating coal with a gross calorific value less than 5700 kcal/kg (23.9 GJ/t) containing more than 31% volatile matter on a dry mineral matter-free basis.

Small-scale coal mining has been existing for thousands of years. But the exponential expansion of international trade began in industrial revolution in Britain in the eighteenth century. The new mines were created in continental Europe and North America and then over the whole world in order to power steam engines. The methods of coal extraction depend on the depth and quality of the seams, the geology, and environmental factors. The two basic methods represent surface mining and deep underground mining. Seams close to the surface, at depths less than approximately 50 m, are used to be surface mined using open cut mining methods. Opencast coal mining recovers a greater proportion of the coal deposit than underground methods. Opencast mines often cover large areas of many square kilometers (Fig. 4.1) and use very large pieces of equipment such as excavators and conveyors. The extraction of coal by an excavator in a detail view is shown in Fig. 4.2. An example of a fossil fueled power station is shown in Fig. 4.3.

Coal is mostly used as a solid fuel to produce heat and electricity through combustion. World coal consumption increased to 8285 million of tones in 2011, but then shows slight declining. Consumption increased in Asia, while Europe has declined. Coal consumption trends 1980–2012 in the world, EU-27, OECD, non-OECD, and selected countries such as the United States, China, and Russia (former USSR to 1991) are shown in Fig. 4.4 and in Table 4.2 in millions of short tonnes (1 short tonne equals 907.18470 kg). Total coal consumption in 2005–2012 in top ten countries with the highest coal consumption in 2012 and their coal reserves in 2011 are shown in Table 4.3. Many countries have to import coal, because their reserves and production are negligible in comparison to their consumption.

The world's leading coal producer and consumer has been China since 1985 with a small decline in 2012. Other countries with notable declines of coal production in 2014

Fig. 4.2 (**a**) Coal extraction in a surface mine with an excavator. (**b**) The extraction of coal by an excavator in a detail view

included Ukraine (−24.1 Mt. due to turmoil in the Eastern Oblasts of Donetsk and Luhansk in the second half of 2014), Indonesia (−16.9 Mt. partly due to current weaker demand for Indonesian coals in China), and Serbia (−10.4 Mt. due to flooding of mines). While production of coking coal reached a new record high of 1064.8 Mt. in 2014, it was unable to counter decreases in production of steam coal and lignite. The following shows Table 4.4, which excludes other specific minor items such as peat, oil shale, and oil sands.

Generally, global production of all primary coal types passed 4 gigatons (Gt) in 1983 (3 Gt in 1972), 5 Gt in 2003, and 8 Gt in 2013. Annual coal production has

Fig. 4.3 (**a**) Fossil-fueled power station for production of electricity and for central heating of neighbor residential sites. (**b**) Temporary coal storage of the fossil fueled power station

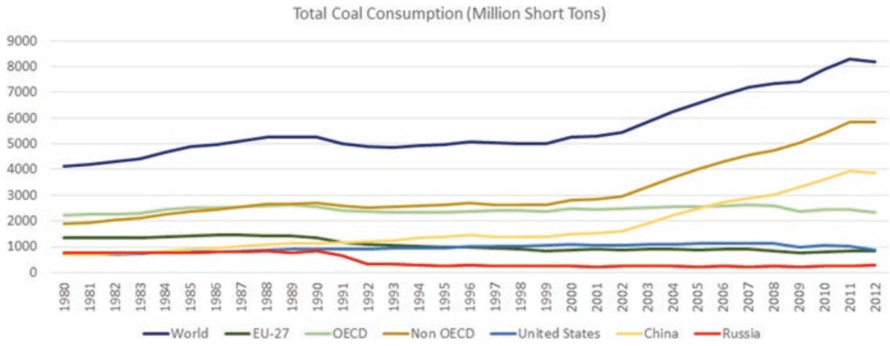


Fig. 4.4 Total coal consumption trends in 1980–2012 in the world, EU-27, OECD, non-OECD, and selected countries such as the United States, China, and Russia (former USSR to 1991). Source: EIA International Energy Statistics, 2016

increased by more than four billion tonnes in the last 30 years and more than twice the level achieved in 1983. Coal will continue to be primarily used for the production of electricity and commercial heat. The percentage of this use in OECD countries was 49.9% in 1971 with the rapid growth to 67.5% in 1983 as replacements for oil after the oil shocks in the 1970s (IEA Coal Information-excerpt, 2015).

In 2012 global emissions of carbon dioxide from fuel combustion increased by 390 Mt. to reach 31.7 Gt. Coal remained the largest source of emissions with an increase 172 Mt. to reach 13.9 Gt in the global emission inventory. OECD coal-based emissions increased from 3.91 to 3.95 Gt in 2013. Extra emissions could be explained as a result of a severe winter, especially in the United States in 2013. It also includes an increase of emissions in Japan as a result of limited electricity generation from nuclear power in 2013. Overall since 1971, coal-related emissions of carbon dioxide have increased from 5.2 to 13.9 Gt in 2012 (passing 8.3 Gt in 1990). Since 2004, coal is the leading source of global carbon dioxide emissions, outstripping those from oil and natural gas and other sources (IEA Coal Information-excerpt, 2015).

4.1.2 Oil as an Energy Source

Oil (petroleum) consists of hydrocarbons and other organic compounds, which are commonly refined into various types of fuels. The name petroleum covers both naturally occurring unprocessed crude oil and petroleum products that are made up of refined crude oil. Crude oil is a fossil fuel, and it exists in liquid form in underground pools, in tiny spaces within sedimentary rocks, and near the surface in tar sands. Petroleum is recovered by oil drilling, which is carried out after structural geology explorations. The pumpjack pumping an oil well and an oil platform in the sea is illustrated in Fig. 4.5. Subsequently, it is refined and separated by distillation, into a large number of final products, from gasoline and kerosene to asphalt and chemical reagents used to make plastics and pharmaceuticals.

Table 4.2 Total coal consumption in the world, EU-27, OECD, non-OECD, and selected countries such as the United States, China, and Russia (former USSR to 1991)

	Total coal consumption (millions of short tonnes)												
Country group	1980	1985	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012
World	4123	4888	5262	4961	5279	6575	6900	7187	7336	7416	7885	8285	8186
EU-27	1335	1439	1333	986	890	886	896	903	851	777	786	825	838
OECD	2230	2530	2559	2320	2482	2574	2578	2631	2577	2363	2457	2432	2348
Non-OECD	1893	2359	2702	2641	2797	4001	4322	4557	4750	5043	5419	5843	5838
United States	703	818	904	962	1084	1126	1112	1128	1121	997	1049	1003	889
China	679	911	1123	1382	1493	2484	2722	2890	3017	3321	3606	3954	3887
Russia[a]	751	779	848	270	253	233	240	230	250	204	244	246	274

Source: EIA International Energy Statistics, 2016

[a]Russia after disintegration of former USSR in 1991, the higher value in 1980–1990 include total coal consumption of former USSR

Table 4.3 Total coal consumption in 2005–2012 in top ten countries with the highest coal consumption in 2012 and estimates of coal reserves in 2011

	Total coal consumption (millions of short tonnes)								Coal reserves
Country	2005	2006	2007	2008	2009	2010	2011	2012	2011
China	2484	2722	2890	3017	3321	3606	3954	3887	126,215
United States	1126	1112	1128	1121	997	1049	1003	889	258,619
India	505	539	587	619	687	699	720	745	66,800
Russia	233	240	230	250	204	244	246	274	173,074
Germany	271	271	281	268	248	256	262	269	44,697
Japan	196	198	208	204	181	206	193	202	383
Australia	153	155	155	154	158	152	147	151	84,217
Poland	150	155	150	149	141	148	153	147	6024
South Korea	88	90	98	111	114	127	140	138	139
Turkey	85	92	109	109	109	106	112	108	9592

Source: EIA International Energy Statistics, 2016

Table 4.4 Total world coal production in dependence on target consumption in 2012–2014 (it excludes other specific minor items such as peat, oil shale, and oil sands)

	Total world coal production in dependence on target consumption		
	2012	2013	2014
Steam coal	5901	6203	6147
Coking coal	976	1038	1065
Lignite	887	835	811
Subtotal	7764	8076	8023

Source: IEA Coal Information-excerpt, 2015

Oil has been used since ancient times. Now it is important across economy, politics, and technology due to the invention of the internal combustion engine and the importance to industrial organic chemistry. Access to oil has been a major factor in several military conflicts for last centuries. During the early twentieth century, oil exploration in North America led to the United States becoming the leading producer, but in the 1960s the United States was surpassed by Saudi Arabia and the Soviet Union. The top oil-producing countries are Russia, Saudi Arabia, and the United States, but about 80% of the world's accessible reserves are located in the Middle East (Saudi Arabia, the United Arab Emirates, Iraq, Qatar, and Kuwait). A portion of the world's reserves exists as unconventional sources, such as bitumen in Canada and extra heavy oil in Venezuela. Oil extraction from oil sands, particularly in Canada, requires large amounts of heat and water, making its net energy content quite low relative to conventional crude oil. Oil sands near the Birch Mountains in Alberta, Canada, are illustrated in Fig. 4.6. The proportion of light hydrocarbons in oil constitution significantly varies among different resources. It ranges from 97% by weight in the lighter oils to 50% in the heavier oil and bitumen oil. Hydrocarbons in crude oil are mostly alkanes (paraffins, 15–60%), naphthenes (30–60%), aromatics

Fig. 4.5 A pumpjack pumping an oil well and an oil platform in the sea. Source: www.pixabay.com

(3–30%), and asphaltics (more than 6%). Other organic impurities contain nitrogen, oxygen, sulfur, and trace amounts of metals such as iron, nickel, copper, and vanadium, but the exact molecular composition varies widely from formation to formation.

The production of crude oil is generally classified by the petroleum industry in dependence on its geographic location, API (American Petroleum Institute) gravity, and sulfur content. The geographic location affects transportation costs to the refinery. From the view of API gravity, light crude oil is more desirable than heavy oil since it produces a higher yield of gasoline. In case of sulfur content, sweet oil commands a higher price than sour oil because it has fewer environmental problems and requires less refining to meet sulfur standards. Each crude oil has unique constitution which is understood by the use of crude oil assay analysis in petroleum laboratories. It is used as pricing references for barrels throughout the world. Examples of the common reference crudes are West Texas Intermediate (a very high-quality oil delivered at Cushing, Oklahoma, for North American oil), Brent Blend (comprising 15 oils from fields of the North Sea), Dubai-Oman (used as benchmark for Middle East sour crude oil), Tapis (from Malaysia, used as a reference for light Far East oil), Minas (from Indonesia, used as a reference for heavy Far East oil), the OPEC Reference Basket (a weighted average of oil blends from various OPEC), Midway-Sunset

Fig. 4.6 Oil (tar or bituminous) sands near the Birch Mountains in Alberta, Canada. Source: Google Earth 2016

Fig. 4.7 Oil refining and transporting with oil tankers. Source: www.pixabay.com

Heavy (used for pricing of heavy oil in California), and Western Canadian Select (benchmark crude oil for emerging heavy, high TAN acidic crudes). The production of crude oil by petroleum industry involves the global processes of exploration, extraction, refining, transporting with oil tankers and pipelines, and marketing (Figs. 4.7 and 4.8).

Consumption of crude oil in the last decades has been significantly pushed by automobile growth and, partly, by industry. But in the future, a lower growth of demand can be indicated by emerging economies concerns, especially in non-OECD countries like China, because oil products are also in competition with alternative

Fig. 4.8 The Houston Ship Channel in Texas with a number of oil transport utilities. Source: pixabay CC0

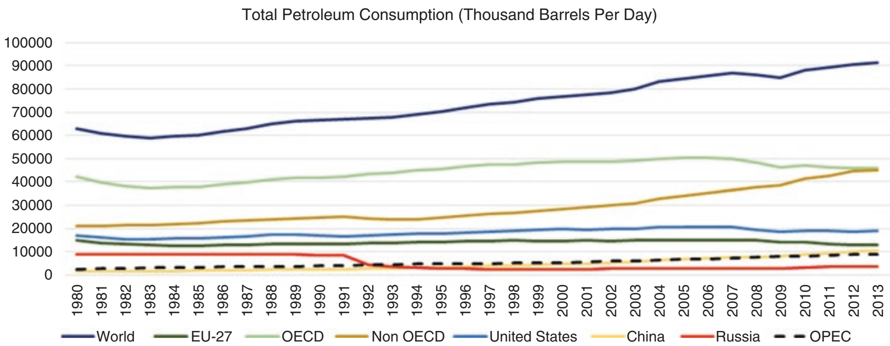


Fig. 4.9 Total petroleum consumption trends in 1980–2013 in the world, EU-27, OECD, non-OECD, OPEC, and selected countries such as the United States, China, and Russia (former USSR to 1991). Source: EIA International Energy Statistics, 2016

cheaper sources, mainly coal and natural gas. Petroleum consumption trends in 1980–2013 in the world, EU-27, OECD, non-OECD, OPEC, and selected countries are shown in Fig. 4.9 and in Table 4.5. Total petroleum consumption in 2005–2012 in top ten countries with the highest petroleum consumption in 2013 and their total oil supply in 2014 are shown in Table 4.6.

The environmental impacts of petroleum are negative due to its toxicity in almost all forms of life. Oil products such as crude oil are closely linked to all aspects of

Table 4.5 Total petroleum consumption in the world, EU-27, OECD, non-OECD, OPEC, and selected countries such as the United States, China, and Russia (former USSR to 1991)

	Total petroleum consumption (thousand barrels per day)									
Country group	1980	1985	1990	1995	2000	2005	2010	2011	2012	2013
World	63,122	60,083	66,541	70,258	76,928	84,588	88,216	89,127	90,392	91,253
EU-27	14,873	12,569	13,387	14,233	14,607	15,079	14,005	13,559	13,067	12,829
OECD	42,032	37,697	41,754	45,401	48,506	50,416	46,998	46,345	45,923	45,994
Non-OECD	21,090	22,386	24,786	24,858	28,422	34,172	41,219	42,783	44,469	45,165
United States	17,056	15,726	16,988	17,725	19,701	20,802	19,180	18,882	18,490	18,961
China	1765	1885	2296	3363	4796	6795	8938	9504	10,175	10,480
Russia	8995	8950	8392	2976	2578	2785	3135	3422	3445	3493
OPEC	2510	3327	3983	4730	5351	6707	8248	8376	8827	9011

Source: EIA International Energy Statistics, 2016

Table 4.6 Total petroleum consumption in 2005–2013 in top ten countries with the highest petroleum consumption in 2013 and their oil supply in 2014

	Total petroleum consumption (thousand barrels per day)									Total oil supply
Country	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
United States	20,802	20,687	20,680	19,498	18,771	19,180	18,882	18,490	18,961	14,021
China	6795	7263	7480	7697	8070	8938	9504	10,175	10,480	4598
Japan	5298	5168	5009	4770	4363	4429	4439	4697	4557	137
India	2550	2702	2888	2957	3068	3305	3461	3618	3660	1011
Russia	2785	2803	2885	2982	2889	3135	3422	3445	3493	10,847
Brazil	2171	2197	2297	2441	2459	2699	2777	2923	3003	2966
Saudi Arabia	1964	2020	2094	2237	2436	2580	2761	2882	2961	11,624
Germany	2624	2636	2407	2533	2434	2467	2392	2389	2435	159
Canada	2296	2294	2389	2317	2230	2326	2357	2403	2374	4383
South Korea	2191	2180	2240	2142	2188	2269	2259	2322	2328	79

Source: EIA International Energy Statistics, 2016

present society, especially for transportation and heating. When burned, petroleum releases carbon dioxide and together with coal is the largest contributor to the increase in atmospheric carbon dioxide. Increasing of carbon dioxide in the atmosphere causes global warming and ocean acidification by the uptake of carbon dioxide from the atmosphere. Also oil spills from tanker ship accidents have damaged natural ecosystems in many parts of the world such as Alaska, the Gulf of Mexico, and other places. Even small oil spills have a great impact on ecosystems due to their spreading for hundreds of miles in a thin oil slick in comparison with oil spills on land that can be rapidly bulldozed around the spill site before most of the oil escapes.

4.1.3 Natural Gas as an Energy Source

Natural gas is one of the cleanest fossil-based fuels that will continue making significant contribution to the world energy economy. Natural gas is plentiful and flexible, which is useful for power generation technologies and local heating systems. The exploration, development, and transport of gas require significant upfront investment and close coordination between investment in the gas and power infrastructure. Natural gas is often informally referred to simply as "gas," especially when compared to other energy sources such as oil or coal.

Natural gas is a mixture consisting primarily of methane with varying amounts of other higher alkanes. Sometimes it contains a small percentage of carbon dioxide, nitrogen, hydrogen sulfide, or rare gases (Table 4.7). Natural gas like oil and coal is essentially derived from the remains of plants and animals that lived millions of years ago. It is formed when layers of decomposing plant and animal matter are exposed to intense heat and pressure supplied by existing under the surface of the Earth over millions of years. The energy stored in the form of chemical bonds originates from the energy that the plants and animals obtained from the sun through the food chain. Before natural gas can be used for power generation or local heating, it must be processed to remove impurities, including water, to meet the specifications of marketable natural gas.

Table 4.7 Typical composition of natural gas

Methane	CH_4	70–90%
Ethane	C_2H_6	0–20%
Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon dioxide	CO_2	0–8%
Oxygen	O_2	0–0.2%
Nitrogen	N_2	0–5%
Hydrogen sulfide	H_2S	0–5%
Rare gases	A, He, Ne, Xe	Trace

Source: http://naturalgas.org/overview/background/, 2016

Fig. 4.10 Remote natural gas well. Source: https://www.flickr.com/photos/25069384@N03/8743405319, 2016

Natural gas deposits are often located near oil deposits, and the gas is mostly extracted by drilling from the Earth's surface. An illustration of the natural gas well is shown in Fig. 4.10. The amount of natural gas is measured in cubic meters or standard cubic feet. In 2009, the US EIA estimated that the world's proven natural gas reserves are around 6289 trillion cubic feet (tcf). Most of the reserves are in the Middle East (40% of total world reserves). Russia has the second-highest amount of proven reserves. The United States has just over 4% of the world's natural gas reserves. After natural gas is extracted, it is transported through pipelines (from 2 to 60 in. in diameter). For example, the continental United States has more than 210 pipeline systems including about 490,850 km (305,000 miles) of transmission pipelines that transfer gas to all states. This system is complemented by more than 1400 compressor stations to ensure that the gas continues on its path, 400 underground storage facilities, 11,000 locations to deliver the gas, and 5000 locations to receive the gas. Natural gas can also be cooled to about −162 °C (−260 °F) and converted into liquefied natural gas (LNG). In this form, natural gas takes up only 1/600 of the volume of its gaseous state and can be transported by specialized insulated tankers to sites that do not have pipelines.

Natural gas is utilized in countless ways for industrial, residential, and transportation purposes. An example of mobile gas turbine used to generate electricity is shown in Fig. 4.11. Natural gas can be also used as an alternative fuel for vehicles that are running cleaner and cheaper to refuel then gasoline or diesel vehicles.

Fig. 4.11 Mobile gas turbine used to generate electricity. Source: www.pixabay.com

Other promising technology is represented by fuel cells where the energy from natural gas is also used to generate electricity. It produces water, heat, and electricity without any other by-products or emissions.

Global production and consumption of natural gas has increasing trend for last decades. While consumption in the OECD rose by a few percent (driven by the United States and Canada), consumption in non-OECD rose more significantly in the last years. The natural gas consumption trends in 1980–2013 in the world, EU-27, OECD, non-OECD, OPEC, and selected countries such as the United States, China, and Russia are illustrated in Fig. 4.12 and Table 4.8. Natural gas consumption in 2005–2013 in top ten countries with the highest natural gas consumption in 2013 and their natural gas production in 2014 is shown in Table 4.9. Besides the price on the market, demand for natural gas was also influenced by mild weather in Europe and by effects of the escalating conflicts between Russia and Ukraine.

4.2 Mapping of Fossil Sources with GPS and GIS

Exploration of local sites with mobile GIS can assess energy sources in a more accurate way and collaborate in both field and office environments. Using mobile GIS enables to improve efficiency and accuracy of field operations and provides

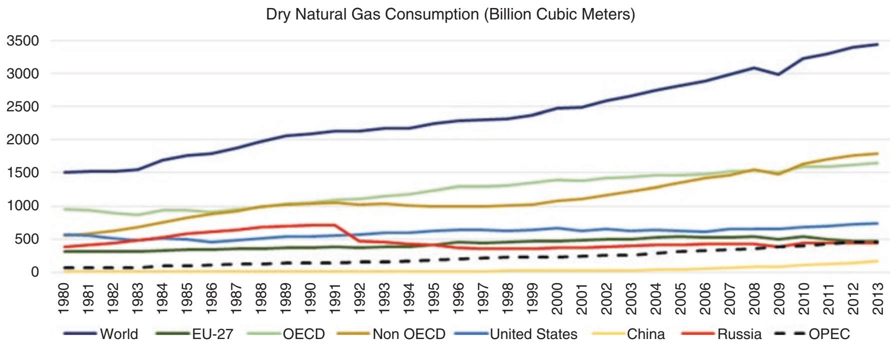


Fig. 4.12 Dry natural gas consumption trends in 1980–2013 in the world, EU-27, OECD, non-OECD, OPEC, and selected countries such as the United States, China, and Russia (former USSR to 1991). Source: EIA International Energy Statistics, 2016

Table 4.8 Dry natural gas consumption in the world, EU-27, OECD, non-OECD, OPEC, and selected countries such as the United States, China, and Russia (former USSR to 1991)

	Dry natural gas consumption (Billion cubic meters)									
Country group	1980	1985	1990	1995	2000	2005	2010	2011	2012	2013
World	1499	1761	2083	2238	2471	2817	3224	3296	3390	3437
EU-27	311	339	363	418	473	533	534	492	475	469
OECD	950	936	1050	1239	1388	1461	1590	1595	1626	1647
Non-OECD	550	824	1033	999	1082	1356	1634	1701	1764	1790
United States	563	489	*543*	629	661	623	682	693	723	741
China	14	13	14	16	25	47	107	131	144	163
Russia	377	575	705	411	370	406	438	434	445	442
OPEC	67	100	141	178	232	314	395	421	453	459

Source: EIA International Energy Statistics, 2016

Table 4.9 Dry natural gas consumption in 2005–2013 in top ten countries with the highest dry natural gas consumption in 2013 and dry natural gas production in 2014

	Dry natural gas consumption (Billion cubic meters)									Production
Country	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
United States	623	615	654	659	649	682	693	723	741	729
Russia	406	431	430	432	382	438	434	445	442	579
China	47	56	71	77	89	107	131	144	163	122
Iran	105	109	113	119	141	145	153	157	157	(in 2013) 161
Japan	88	97	106	104	103	109	126	127	127	5
Canada	89	93	86	83	85	80	86	100	104	151
Saudi Arabia	71	73	74	80	78	88	92	99	100	102
Germany	91	93	89	92	86	94	86	85	88	10
United Kingdom	96	91	92	95	88	94	81	78	77	39
Italy	86	84	85	85	78	83	78	75	70	7

Source: EIA International Energy Statistics, 2016

rapid data collection and seamless data integration. Field mapping and data collection are supported by a number of mobile computing tools, which are used to be extended by high-sensitivity GPS receivers, cameras, and professional laser rangefinders, which can measure slope distance, inclination, and azimuth and calculate horizontal and vertical distance. Mobile GIS includes capabilities for capturing, editing, and displaying of thematic map layers. Its GIS extensions can manage GPS data and data from optional sensors. There is also geodatabase connectivity through mobile networks in the mobile GIS environment. Thus, mobile GIS can be a part of an enterprise GIS solution in order to perform reliable field data collection with internal and external sensors, share enterprise data for rapid decision-making, increase the accuracy and validity of geodatabase, and improve the productivity of field research (Table 4.10).

Table 4.10 A list of selected mobile GISs and other related software tools

GIS	Description and the key features	Website and development
ArcPad (ESRI) [commercial]	Mobile field mapping and data collection software, which includes advanced GIS and GPS capabilities for capturing, editing, and displaying geographic information. It can manage external sensors and enables data synchronization with ArcGIS Server 10.x and ArcGIS Online feature services	http://www.esri.com/software/arcgis/arcpad Mobile GIS is supported by Windows Mobile (5.0, 6.0, 6.1, and 6.5), Windows Tablets (8.1 and 10), and Windows Desktop (XP, Vista, 7, 8.1, and 10) All customizations for ArcPad can be performed on the Windows Desktop with ArcPad Studio, and deployed with ArcPad on the mobile device
ArcGIS for Windows Mobile (ESRI) [commercial]	An application that delivers GIS capabilities and data from centralized servers to a range of mobile devices. It supports simplified mapping, spatial query, sketching, limited tools for GIS editing, and basic GPS functionality	http://www.esri.com/software/arcgis/arcgismobile Mobile GIS is supported by Windows Embedded Handheld (6.0, 6.1, and 6.5) and Windows Desktop (XP, Vista, 7, 8.1, and 10). It comes with a ready-to-deploy application and a software development kit. NET SDK for building custom applications
Apps for smartphones and tablets (ESRI) [commercial]	A few applications for sharing public maps (Explorer for ArcGIS, Web AppBuilder, AppStudio), sharing maps within an organization (Explorer for ArcGIS), and geographic data editing in the field (Collector and Web AppBuilder for ArcGIS, ArcGIS web application templates)	http://www.esri.com/software/arcgis/arcgis-app-for-smartphones-and-tablets Mobile applications are supported by smartphones and tablets running on various software platforms. Then installations also support a number of languages and national data formats. More detail information is available on ESRI Web pages
QGIS (previously known as Quantum GIS) [open source]	A free and open-source geographic information system, which offers geospatial data management. Limited functionality is also supported on mobile platform	http://www.qgis.org/en/site/ QGIS is freely available on Windows, Linux, MacOS X, BSD, and android. Binary packages (installers) for current versions can be downloaded from http://www.qgis.org/en/site/forusers/download.html

Using mobile GIS on field computers with GPS advanced tools can benefit from availability of a computing system, GPS data collection, and sharing data with other external sensors such as laser rangefinders and cameras. It can be helpful for terrain exploration of the fossil fuels and their environmental effects during the extraction and remediation. Using new computing devices with GPS technology and internal laser rangefinders is setting new mapping and GIS industry standards with real-time decimeter level positioning accuracy. Programming capabilities enable to create a number of analytical functions and modeling tools that are best fitted to the area of interest. New developments in the mobile GIS have enabled the geodatabases to be taken into the field as digital maps providing field access to enterprise geographic information. It offers terrain researches to add real-time information to their database and analytical applications, speeding up analysis, display, and decision-making by using actual, more accurate spatial and temporal data. Thus, the mobile GIS can support online field mapping, asset inventories, inspections, incident reporting, and a wide range of GIS methods recently processed in the desktop GIS environment. It is expected that feature powerful mobile GISs with more accurate sensors will be able to provide even more complex data analysis.

The global navigation satellite system enables high accuracy positioning using satellite signals that meet the requirements of real-time accuracy, continuity of signal, and signal coverage as wide as possible. The system is very useful for mineral prospecting and mining besides road, rail, air, and maritime transport and other areas such as telecommunications, geodesy, agriculture, and environmental Earth observation. The market is growing, and it is expected that in 2020 will be operating for about three billion satellite navigation receivers.

Global Positioning System (GPS) managed by the United States is at present the only one fully operating satellite navigation system. It provides users with positioning, navigation, and timing services. This system consists of three segments: the space segment, the control segment, and the user segment. The US Air Force develops, maintains, and operates the space and control segments. The space segment consists of a constellation of satellites transmitting radio signals to users. The United States is committed to maintaining the availability of at least 24 operational GPS satellites, 95% of the time. To ensure this commitment, the Air Force has been flying more operational GPS satellites. GPS satellites fly in medium Earth orbit at an altitude of approximately 20,200 km, and their constellations are arranged into six equally spaced orbital planes surrounding the Earth. Each satellite circles the Earth twice a day. As of June, 2016, the GPS constellation is a mix of old and new satellites with 31 operational satellites. The GPS control segment consists of a global network of ground facilities that track the GPS satellites, monitor their transmissions, perform analyses, and send commands and data to the constellation (Fig. 4.13). The user segment consists of the GPS receiver equipment, which receives the signals from the GPS satellites and uses the transmitted information to calculate the user's three-dimensional position and time. GPS satellites provide service to civilian and military users. The civilian service is freely available to all users on a continuous, worldwide basis. The military service is available to US and allied armed forces as well as approved government agencies. The generations of

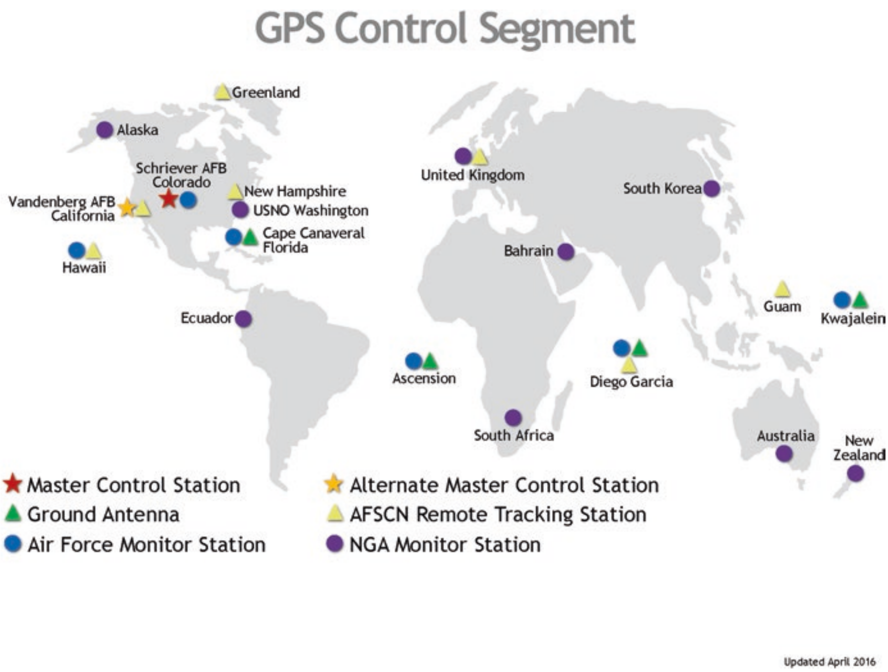


Fig. 4.13 The map schema of the GPS control segment. Source: www.gps.gov, 2016

Fig. 4.14 GPS IIF in production phase (on the left side) and GPS IIF in the operational phase (on the right side). Source: Boeing media-room, 2016

GPS satellites consist of legacy satellites (BLOCK IIA, 0 operational; BLOCK IIR, 12 operational) and modernized satellites (BLOCK IIR-M, 7 operational; BLOCK IIF, 12 operational; GPS III: in production). A satellite BLOCK IIF is in production phase and the operational phase is illustrated in Fig. 4.14.

EGNOS (European Geostationary Navigation Overlay Service) is a European project that provides a form of differential correction signal for GPS. Corrections are provided for the territory of Europe in order to eliminate errors by differential signal processing in receivers, which gives more precision to positioning. The system is composed of 34 ground Ranging and Integrity Monitoring Station (RIMS), which are located in Europe and continuously monitors the data transmitted from satellites in the GPS. The received result is continuously transmitted through a secure data network to one of the Master Control Centers (MCC), where the data is used to estimate errors caused by the state of Earth's atmosphere. The resulting information is then transmitted through the three networks of broadcasters to three satellites in geostationary orbit. These satellites return data back to Earth, where the receiver corrects them according to data received from GPS satellites. In practice, the error should be at least 99% measuring less than 1.5 m. The system is being developed and managed by the European Space Agency (ESA), European Commission (EC), and European Organization for the Safety of Air Navigation (EUROCONTROL).

GLONASS (Global Navigation Satellite System) managed by the Russian Federation Government is analogy to the US GPS. Both systems share the same principles in the data transmission and positioning methods. The operational space segment of GLONASS consists of 21 satellites in three orbital planes, with three on-orbit spare ones. Its active satellites continuously transmit coded signals, which can be received by users anywhere on the Earth's surface to identify their position and velocity in real time based on ranging measurements.

GALILEO Global Navigation Satellite System is planned as an autonomous European Global Navigation Satellite System (GNSS), which should be similar to the US GPS. Its development is actually ensured by the European Union (EU), represented by the European Commission (EC) and European Space Agency (ESA). System Galileo was originally planned to be operational by 2010, but its start was postponed several times. The fully deployed Galileo system consists of 30 satellites (27 operational + 3 active spares), positioned in three circular medium Earth orbit (MEO) planes at 23,222 km altitude above the Earth and at an inclination of the orbital planes of 56° with reference to the equatorial plane. Once this is achieved, the Galileo navigation signals will provide good coverage even at latitudes up to 75° north. It will provide five basic services:

- Open service will provide free of charge superior position and timing performance.
- Safety of life service will be offered and guaranteed to the critical transport community, such as aviation and maritime, delivering enhanced performance that includes the provision of the integrity function including a warning of system malfunction that will reach the user in a given alarm time.
- Commercial service will provide access to two additional encrypted signals to enable users improving of accuracy.
- Public regulated service will provide positioning and timing to specific users requiring a high continuity of service, with controlled access.
- Search and rescue service will represent Europe's contribution of to the international COSPAS-SARSAT cooperative effort on humanitarian search and rescue activities.

All services will have great potential especially in transport, but still offers a wide range of use in other areas where it will increase security, accuracy, and comfort such as energy industry, environmental protection, banking, and agriculture.

BeiDou Navigation Satellite System (Compass) is a Chinese project of a satellite navigation system that is created as independent system consisting of two project generations: BeiDou 1 and BeiDou 2. BeiDou 1 has been working since 2000 and provides services in China and adjacent countries. The next project, BeiDou 2, is still under construction and should be finished in 2020. It will use five geostationary orbit satellites and 30 low orbit satellites in order to provide signal all around the world.

RNSS (Indian Regional Navigational Satellite System) is managed by Indian Space Research Organization as a fully civilian system under control of Indian government. The project was launched in 2006. The complete configuration will consist of seven satellites (three satellites in geostationary orbit).

QZSS (Quasi-Zenith Satellite System) is a proposed three-satellite regional time transfer system as an enhancement for existing GPS within Japan. The system was launched in 2010. The satellites would be placed in a periodic highly elliptical orbit.

4.3 Mapping of Fossil Sources with Remote Sensing and GIS

Remote sensing is defined as collecting and interpreting information about the environment and the surface of the Earth from distance, primarily by sensing radiation that is naturally emitted or reflected by the Earth's surface or from the atmosphere or by sensing signals transmitted from a device and reflected back to it. Remote sensing is used to be divided into active and passive methods. Active methods include systems such as radar and LiDAR (Light Detection and Ranging) that produce electromagnetic radiation and measure its reflection back from a surface. Passive methods deal with satellite imaging and aerial photography that detect energy naturally reflected or emitted by objects.

Particularly the remote sensing systems deployed on satellites can provide a repetitive view of the Earth's surface, which is invaluable for exploration of long-term land cover changes. In case of passive methods, the optical regime from visible spectrum through thermal spectrum of the electromagnetic radiation depends on two source of radiation: the Sun and the Earth. The radiation collected in the visible to shortwave infrared spectrum originates from the Sun. A part of this radiation is reflected at the Earth's surface, and a part is scattered by the atmosphere, without reaching the Earth. The radiation collected in the thermal infrared spectrum is emitted directly by the Earth's surface. A number of applications in remote sensing have been developed in the context of research projects dealing with climate change, land cover dynamics, and environmental risk assessment. It began when the Landsat Multispectral Scanner System (MSS) provided a consistent set of high-resolution Earth images to the scientific community. Now the Landsat project represents the world's longest continuously acquired collection land remote sensing data. Four decades of imagery give a unique resource for research in those who work in geology,

Fig. 4.15 A timeline of the Landsat missions. Source: USGS, 2016, http://landsat.usgs.gov

forestry, agriculture, regional planning, and assessment of energy sources. As a joint initiative between the US Geological Survey (USGS) and NASA, the Landsat project and the data it collects support government, commercial, industrial, civilian, military, and educational communities throughout the United States and worldwide. More detailed information is on Web pages: http://landsat.usgs.gov. A timeline of Landsat missions is shown in Fig. 4.15. The first civilian Earth observation satellite ERTS-1 (Earth Resources Technology Satellite) was launched in 1972. The ERST-1 was later renamed Landsat 1, and the launches of Landsat 2, Landsat 3, and Landsat 4 followed in 1975, 1978, and 1982, respectively. Landsat 5 was launched in 1984 and delivered high-quality, global data of Earth's land surfaces for more than 28 years. It gives an opportunity to explore land cover changes captured by identical sensors in long-term period. The next satellite Landsat 6 failed to achieve orbit in 1993, but the Landsat program continued by Landsat 7 (successfully launched in 1999) and Landsat 8 (launched in 2013), which continue to provide daily global data. Now images from Landsat satellites are provided free to the public by the Department of the Interior's US Geological Survey. Landsat images also provide standards for a number of new applications such as Timelapse powered by Google, or ChangeMatters Viewer, which is a commercial product of ESRI. Both applications can utilize the global time-lapse video showing changes to our planet visible from Landsat satellite imagery.

The latest Landsat 8's Operational Land Imager (OLI) improves on past Landsat sensors and preserves measurement compatibility with previous Landsat missions, in order to have comparable images for long-term land cover studies. The OLI instrument uses a new sensor, which aligns the imaging detector arrays along Landsat 8's focal plane allowing it to view across the entire swath, 185 km cross-track field of view. The OLI collects data from nine spectral bands, where seven of them are consistent with the Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors in earlier Landsat satellites. The Thermal Infrared Sensor (TIRS) conducts thermal imaging and is registered to OLI data to create radiometrically, geometrically, and terrain-corrected datasets. The TIRS only provides Landsat data continuity with one band, band 10. Visual comparison of Landsat spectral bands from all missions is shown in Fig. 4.16, which includes spectral bands

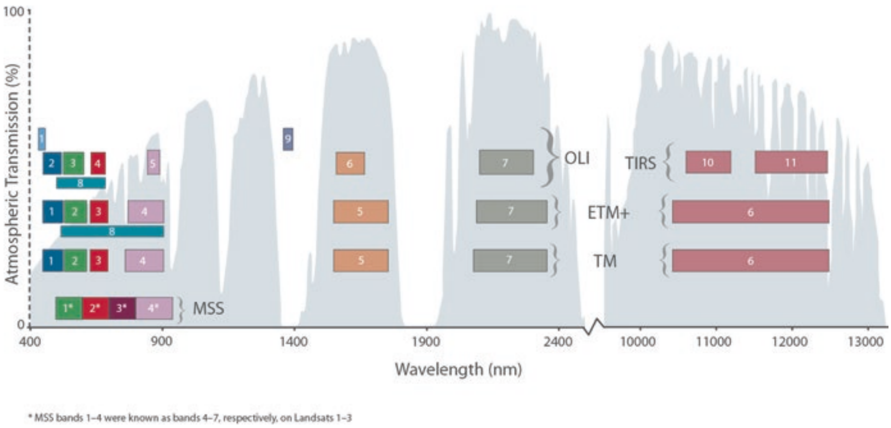


Fig. 4.16 Visual comparison of Landsat spectral bands for Landsat Multispectral Scanner (MSS) on Landsat 1–3, Thematic Mapper (TM) on Landsat 4–5, Enhanced Thematic Mapper Plus (ETM+) on Landsat 7, and OLI together with TIRS on Landsat 8 (atmospheric transmission values were calculated using the model MODTRAN for a summertime mid-latitude hazy atmosphere). Sources: NASA, 2016, http://landsat.gsfc.nasa.gov/

Table 4.11 Landsat 8 Operational Land Imager (OLI) bands and Thermal Infrared Sensor (TIRS) bands

OIL and TIRS spectral bands	Wavelength (μm)	Useful for mapping
Band 1—coastal aerosol	0.43–0.45	Coastal and aerosol studies
Band 2—blue	0.45–0.51	Bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation
Band 3—green	0.53–0.59	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 4—red	0.64–0.67	Discriminates vegetation slopes
Band 5—near infrared (NIR)	0.85–0.88	Emphasizes biomass content and shorelines
Band 6—shortwave infrared (SWIR) 1	1.57–1.65	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 7—shortwave infrared (SWIR) 2	2.11–2.29	Improved moisture content of soil and vegetation and thin cloud penetration
Band 8—panchromatic	0.50–0.68	15 m resolution, sharper image definition
Band 9—Cirrus	1.36–1.38	Improved detection of cirrus cloud contamination
Band 10—TIRS 1	10.60–11.19	100 m resolution, thermal mapping and estimated soil moisture
Band 11—TIRS 2	11.5–12.51	100 m resolution, improved thermal mapping and estimated soil moisture

Source: USGS 2016, http://landsat.usgs.gov/best_spectral_bands_to_use.php

from Landsat Multispectral Scanner (MSS) on Landsat 1–3, Thematic Mapper (TM) on Landsat 4–5, Enhanced Thematic Mapper Plus (ETM+) on Landsat 7, and OLI together with TIRS on Landsat 8. The detailed information about all Landsat bands are shown in Tables 4.11, 4.12 and 4.13.

Table 4.12 Landsat 4–5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+)

TM and ETM+ spectral bands	Wavelength (μm)	Useful for mapping
Band 1—blue	0.45–0.52	Bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation
Band 2—green	0.52–0.60	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 3—red	0.63–0.69	Discriminates vegetation slopes
Band 4—near infrared	0.77–0.90	Emphasizes biomass content and shorelines
Band 5—shortwave infrared	1.55–1.75	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 6—thermal infrared	10.40–12.50	Thermal mapping and estimated soil moisture
Band 7—shortwave infrared	2.09–2.35	Hydrothermally altered rocks associated with mineral deposits
Band 8—panchromatic (Landsat 7 only)	0.52–0.90	15 m resolution, sharper image definition

Source: USGS 2016, http://landsat.usgs.gov/best_spectral_bands_to_use.php

Table 4.13 Landsat Multispectral Scanner (MSS) and its utilization on Landsat 1, 2, and 3 and Landsat 4 and 5

Landsat MSS 1,2, and 3 spectral bands	Landsat MSS 4 and 5 spectral bands	Wavelength (μm)	Useful for mapping
Band 4—green	Band 1—green	0.5–0.6	Sediment-laden water, delineates areas of shallow water
Band 5—red	Band 2—red	0.6–0.7	Cultural features
Band 6—near Infrared	Band 3—near infrared	0.7–0.8	Vegetation boundary between land and water and landforms
Band 7—near infrared	Band 4—near infrared	0.8–1.1	Penetrates atmospheric haze best, emphasizes vegetation, boundary between land and water, and landforms

Source: USGS 2016, http://landsat.usgs.gov/best_spectral_bands_to_use.php

The National Satellite Land Remote Sensing Data Archive (NSLRSDA) at the US Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center holds the rich collection of Landsat data in the world. Currently it holds more than three million Landsat scenes that Landsat satellites have acquired from across the globe for more than four decades. As examples, geographical presentations of scenes that are archived at the EROS are shown in Fig. 4.17 for Landsat 1 MSS in 1973 and for Landsat 8 OLI and TIRS in 2014. The complete presentation of the USGS Landsat Global Archive is available on the Web page: http://landsat.usgs.gov/USGSLandsatGlobalArchive.php. The images are sorted by date and then satellite and then sensor, because most years have multiple maps associated with several

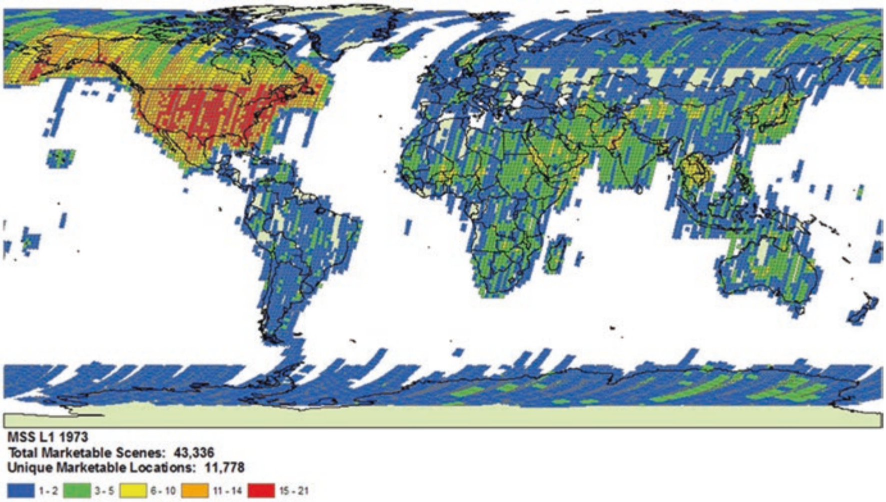


Fig. 4.17 Geographical presentations of scenes that are archived at the EROS for Landsat 1 MSS in 1973. Source: USGS, 2016, http://landsat.usgs.gov/documents/StateOfTheArchive_web.pdf

satellites and sensors. It shows only images held at the USGS EROS Center at time of file creation, but other images can be completed from International Ground Stations that downlinked Landsat data over the years. The Landsat Global Archive Consolidation (LGAC) program started in 2010. Its goal is to consolidate the Landsat archives of all stations worldwide into the USGS EROS Archives (Fig. 4.18).

Landsat images play an important role in identifying and assessment of new energy sources and mitigating the human and environmental impact of energy development. The archive data including more than 40 years of imagery can support decision-makers to monitor the environmental impact of mining and energy generation and track ecological recovery after operations end. The infrared and visible measurements together assist energy companies in identifying minerals on the surface. Farmers can estimate the health of biofuel crops and natural vegetation near dams and mining sites. Scientists and managers from around the world can use data from the archives for a variety of applications and research programs. Besides the USGS EROS Archives, there are many other data sources dealing with satellite imagery, aerial photographs, and LiDAR/radar data over the world. A list of selected satellite imagery data sources is shown in Table 4.14.

Preprocessing of remote sensing data is dealing with feature extraction, radiometric and atmospheric correction, and geometric transformation. But each project requires specific attention and individual preprocessing decisions in dependence on source images and target applications. While the feature extraction depends on a source of images, radiometric and atmospheric correction includes a set of techniques related to the sensitivity of the sensor, topography and sun angle, and atmospheric scattering

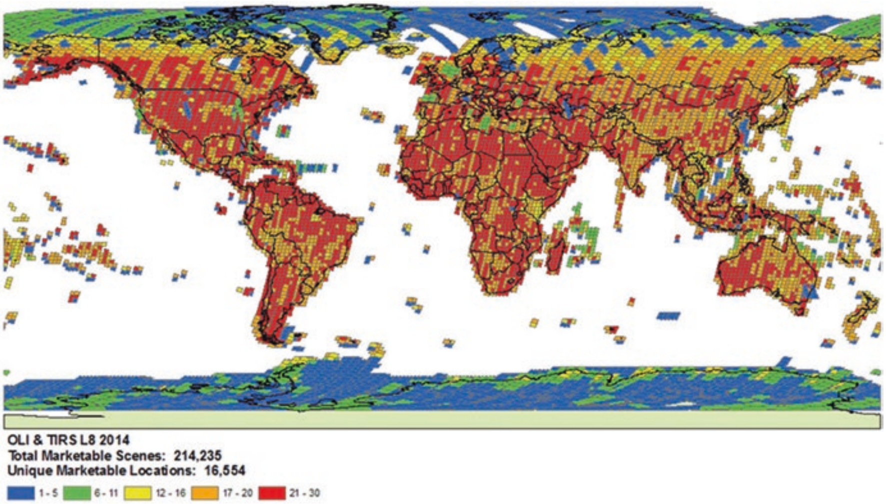


Fig. 4.18 Geographical presentations of scenes that are archived at the EROS for Landsat 8 OLI and TIRS in 2014. Source: USGS, 2016, http://landsat.usgs.gov/documents/StateOfTheArchive_web.pdf

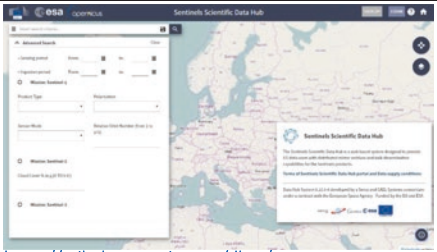
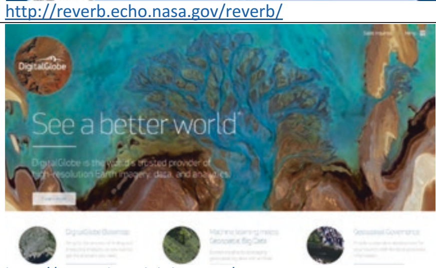
and absorption. The geometric transformation is used to provide spatial correction by a digital terrain model and to bring an image into registration with selected map coordinates. Because preprocessing changes original data, it is recommended to use only those methods that are essential to obtain target results.

After an initial stage of preprocessing data, advanced methods for image classification are mostly applied to explore remote sensing data. Images can be classified based on many distinguishable cover types that are specified by the user such as land cover classes based on geology, major vegetation types, vegetation condition, disturbed areas, or land-use changes. By comparing pixels to one another and to pixels of known identity, the classifier can assemble groups of similar pixels into classes that are associated with explored categories. These classes create regions on an image, which are transformed into a mosaic of uniform parcels, each identified by a color. The pixels in each class are spectrally more similar to one another than they are to pixels in other classes. Image classification techniques in remote sensing are used to be divided into supervised and unsupervised classification.

In the unsupervised classification, pixels are grouped based on their spectral properties into clusters. The user selects the digital image bands, the number of clusters to generate, and the classification algorithm such as K-means or ISODATA. With this information, the unsupervised classification algorithm generates clusters that have to be manually attached to land cover classes. This classification is commonly used when no sample sites exist.

In the supervised classification, the user selects representative samples and training sites, for each land cover class in the digital image. This information is used by

Table 4.14 A list of selected satellite imagery data sources

Data sources	The key features	Website
Earth Explorer (USGS)	-access to Landsat satellite data (the USGS EROS Archives), -ASTER image data, -Shuttle Radar Topography Missions global Digital Elevation Models, -Hyperion's hyperspectral data, -MODIS & AVHRR land surface reflectance and disperse Radar data.	 http://earthexplorer.usgs.gov/
Sentinel Mission (ESA)	-Sentinel 1 day and night radar imaging for land and ocean services (Sentinel 1A, Sentinel 1B), -Sentinel 2 high-resolution optical imaging for land services (Sentinel 2), -Sentinel 3 ocean and global land monitoring services (Sentinel 3A), (a number of Sentinels are planned to be lunched in the future).	 https://scihub.copernicus.eu/dhus/ .
CLASS (NOAA)	-POES, DMSP, GOES, MetOp, Jason-2 data, and selected reanalysis data, -it will archive data collections from the NPP, JPSS (formerly NPOESS), GOES-R, Jason-3, and planned Earth-based observing systems include NEXRAD products.	 http://www.class.ngdc.noaa.gov/saa/products/welcome
Reverb (NASA)	-data from Aqua, Terra, Aura, TRMM, Calipso, NASA DC, JASON, ENVISAT, ALOS, METEOSAT, GOES, ICESAT, GMS, Landsat, NIMBUS, SMAP, RADARSAT, NOAA satellites.	 http://reverb.echo.nasa.gov/reverb/
DigitalGlobe (DigitalGlobe)	-the largest commercial satellite data supplier in the world with downloadable: -data samples from the newly launched satellites, -data samples in fields such as exploration, engineering, land management and simulation, -huge amount of technical information.	 http://www.digitalglobe.com/

the supervised classification algorithm to identify the land cover classes in the image. The supervised classification of land cover is based on the spectral signature defined in the training set. The digital image classification software determines each class on what it resembles most in the training set. The mostly used supervised classification algorithms are maximum likelihood and minimum distance classification.

Described pixel-based classification techniques generate groups of square classified pixels. New object-based image classification is different in that it generates objects of different shape and scale. This process is called multiresolution segmentation, which creates homogenous image objects by grouping pixels. These objects are more meaningful than the standard pixel-based segmentation because they can be classified based on texture, context, and geometry. The object-based techniques are favored for very high spatial resolution images, where objects are made up of several pixels. In addition, object-based image classification can take advantage of both spectral and contextual information in the remotely sensed imagery, which brings higher accuracy to classification.

Satellite and aerial imagery can provide even more answers for assessment of energy sources, environmental change, weather forecasting, disaster management, and other remote sensing applications. Remote sensing software processes images and provides solutions to local or global issues. Applications in geology include bedrock and lithological and structural mapping, where multispectral spectral reflectance has provided valuable information on rock composition while radar has also been useful in studying surface roughness. Other applications deal with extracting mineral deposits with hyperspectral remote sensing, where having more spectral bands gives potential to map more minerals in dependence on their chemical composition. Many applications are focused on detecting land cover/use types for decision-making and monitoring the environment for protection.

4.4 Environmental Effects of Fossil Fuel Use

Fossil fuels such as coal, oil, and gas are currently the world's primary energy source, which have increasingly fueled global economic development for a few last centuries. Fossil fuels are finite resources, and their combustion irreparably harms the environment and is responsible for greenhouse gas emissions. These gases can insulate the planet and may cause catastrophic changes in the Earth's climate. Recently, there are only partial solutions for reduction of greenhouse gas emissions over the world such as energy efficiency, nuclear energy as a zero-carbon alternative for electricity generation, renewable energy, and carbon capture and storage.

The energy supply industry is the largest contributor to global greenhouse gas emissions. It attributed approximately 35% of total anthropogenic emissions in 2010 and accelerated from 1.7% per year in 1990–2000 to 3.1% in 2000–2010. The higher demand for power, heat, and transport services followed by a higher share of coal in the global fuel mix were the main contributors to this trend. The energy supply industry converts over 75% of the total primary energy into other forms such as electricity, heat, refined oil products, coke, and natural gas. Including non-energy use, the industry consumes 84% of final use of coal and peat, 26% of petroleum products, 47% of natural gas, 40% of electricity, and 43% of heat. Transportation consumes 62% of liquid fuels final use. The building sector is responsible for 46% of final natural gas consumption, 76% of combustible renewables and waste, 52% of electricity use, and 51% of heat. Energy losses assessed as the difference between the energy inputs and outputs are estimated more than 29% of total primary energy supply, which also includes the relatively low average global efficiency of energy conversion, transmission, and distribution processes, 37% efficiency for fossil fuel power production and 83% for fossil fuel district heat generation. Between 2000 and 2010, the total primary energy supply grew by 27% globally, 2.4% per year, while for the regions it was 79% in Asia, 47% in Middle East and Africa, 32% in Latin America, and 13% in economies in transition. It was nearly stable for the countries of the OECD. After 2010, the growth was slower, about 2% per year over 2010–2012 in Asia, Middle East and Africa, and Latin America and even declining in economies in transitions and OECD countries (Fig. 4.19) (IPCC, 2014: Climate Change 2014).

The energy market in Asia differs considerably from other markets. This region accounted a high increment for fossil fuels in the last decades. In particular, China doubled the total primary energy supply between 2000 and 2010 and became the

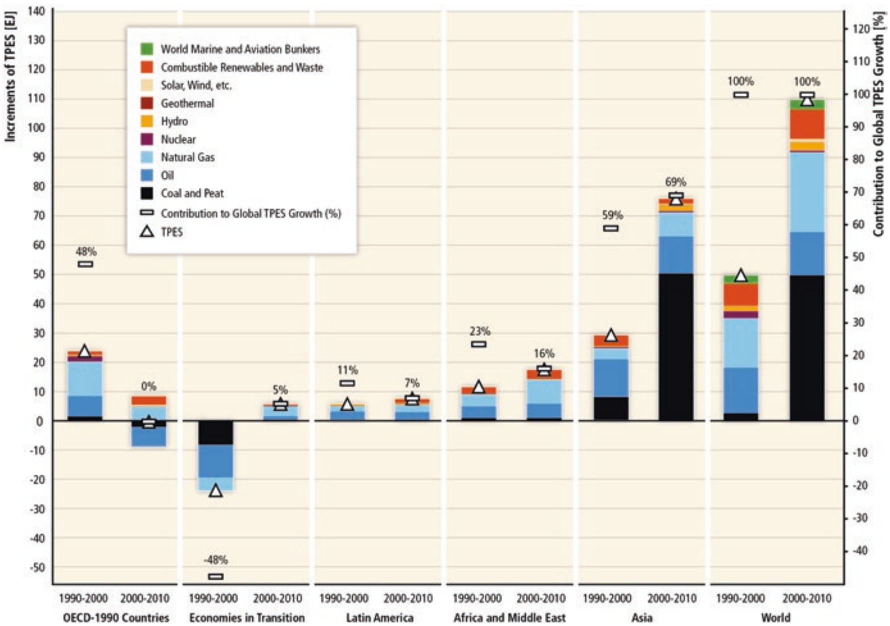


Fig. 4.19 Contribution of energy sources to regional and total primary energy supply (TPES) increments (modern biomass contributes 40% of the total biomass share). Source: IPCC, 2014: Climate Change 2014

leading energy-consuming nation and coal producer. Thus, power generation remains the main global coal renaissance driver in China (47% of world 2012 production), followed by the United States, Australia, Indonesia, India, and other countries. The energy supply industry accounts for 49% of all energy-related greenhouse gas emissions, while remaining energy-related emissions occur in the consumer sectors in 2010. According to emission database EDGAR (Emission Database for Global Atmospheric Research, which provides global past and present-day anthropogenic emissions of greenhouse gases and air pollutants by country and on spatial grid), global greenhouse gas emissions from energy supply industry increased by more than 35% in 2000–2010 and grew on average 1% per year, which was faster than global anthropogenic greenhouse gas emissions (Fig. 4.20). In addition to the predominant carbon dioxide emissions, other emitted emissions involved methane, of which 31% comes from coal and gas production and transmission, and indirect nitrous oxide, of which 9% comes from coal and fuelwood.

Oil is the world's primary fuel source for transportation and chemical industry. Besides the environmental degradation caused by oil spills and extraction, combustion of its products is a major source of greenhouse gas emissions. Also release of fine particulates can lead to serious respiratory problems. Heavier crude oils, especially those extracted from tar sands and shale, require the use of extra energy-intensive methods that result in more emissions and larger environmental degradation in comparison to conventional oil. Unfortunately, extraction of crude oils expands,

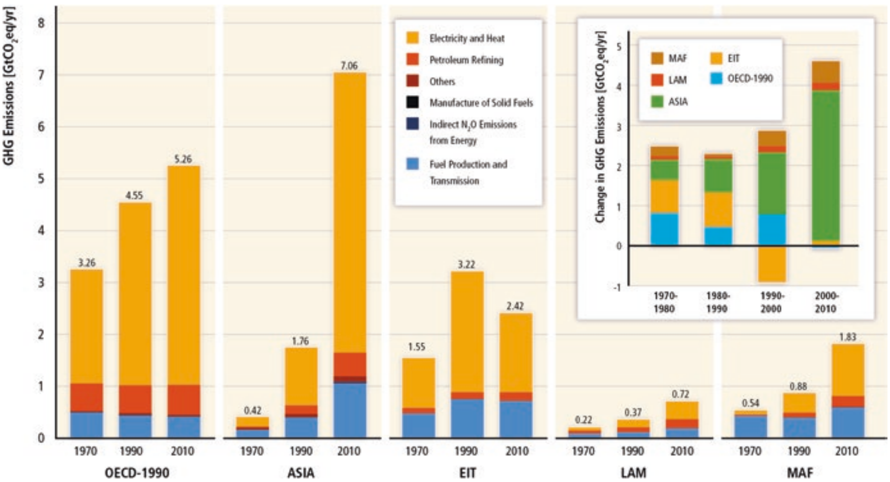


Fig. 4.20 Energy supply industry greenhouse gas (GHG) emissions by subsectors and regions: OECD countries, Asian countries, economies in transition (EIT), Africa and the Middle East (MAF), and Latin America (LAM). The graph on the right side shows contribution of different regions to decadal emissions increments. Source: IPCC, 2014: Climate Change 2014; Emissions Database EDGAR; IEA

because conventional oil from underground reservoirs runs out, and more oil producers have to turn to unconventional sources such as tar sands and oil shale.

Combustion of natural gas is cleaner than coal and oil, with almost zero sulfur dioxide emissions and far fewer nitrogen oxide and particulate emissions. Natural gas releases almost 30% less carbon dioxide than oil and 43% less than coal. Like other fossil fuels, also natural gas is responsible for approximately 27% of greenhouse gas emissions. Natural gas is primarily composed of methane, which is a greenhouse gas that is more than 20 times as potent as carbon dioxide. Thus, capturing and burning the gas, which is also generated by the decomposition of municipal waste in landfills and manure from livestock production, prevent the methane from being released into the atmosphere directly.

Based on the emissions database EDGAR, the global carbon dioxide emissions per region from fossil fuel use and cement production is shown in Fig. 4.21. Carbon dioxide emissions from fossil fuel use and cement production in the top five emitting countries and the EU are illustrated in Fig. 4.22. Finally, the combustion of coal and partially oil releases air pollutants such as acid rain-inducing sulfur dioxide, nitrogen oxides (NOx), and mercury. The extraction is used to be very damaging to the environment, often resulting in the destruction of vegetation and topsoil and potentially contamination of rivers and streams by mine wastes. Technology focused on carbon capture and storage (CCS), where carbon is separated from coal and injected underground for long-term storage, could theoretically be used to mitigate the coal industry's greenhouse gas emissions. It is proven as a way to reduce greenhouse gas emissions from commercial power plants.

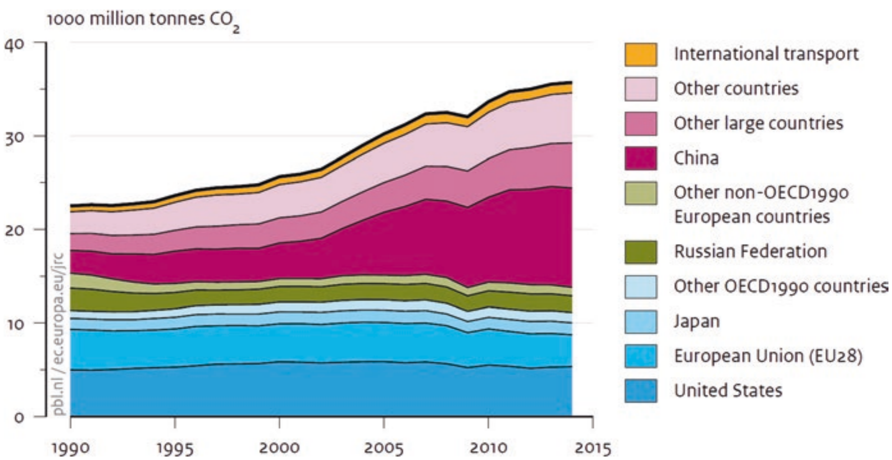


Fig. 4.21 Global carbon dioxide emissions per region from fossil fuel use and cement production. Source: Trends in global carbon dioxide emissions: 2015 Report of the Netherlands Environmental Assessment Agency

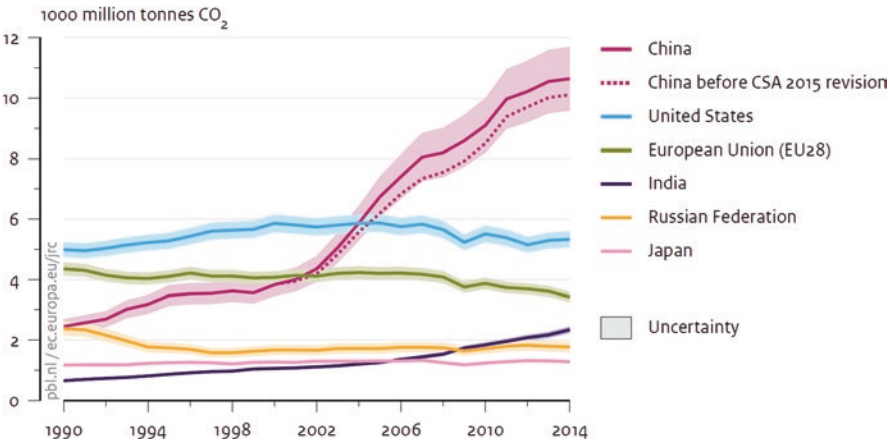
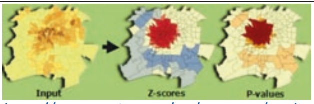
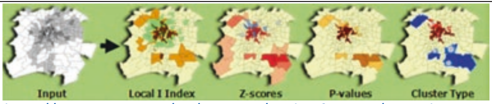
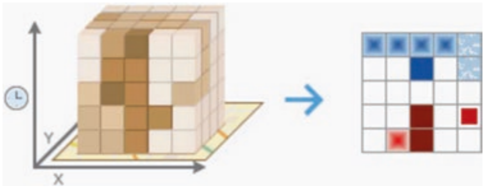
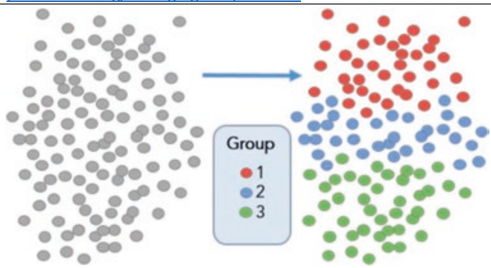


Fig. 4.22 Carbon dioxide emissions from fossil fuel use and cement production in the top five emitting countries and the EU. Source: Trends in global carbon dioxide emissions: 2015 Report of the Netherlands Environmental Assessment Agency

4.5 Integration of Spatial and Temporal Data in GIS

Spatial-temporal analysis in assessment of energy sources offers additional insight into environmental processes at a variety of scales. Hypotheses at the landscape level can now be generated and tested by combining spatial-temporal analyses and models. Advanced methods are necessary for changes in spatial patterns to be identified. These methods are mostly implemented in new versions of GIS software such as Hot Spot Analysis (Getis-Ord Gi* statistic), Cluster and Outlier Analysis (Anselin Local Moran's I statistic), Emerging Hot Spot Analysis, and Grouping Analysis in ArcGIS Pro (Table 4.15). The spatial statistical tools contain a number of other statistical methods for analyzing spatial distributions, patterns, processes, and relationships. Unlike traditional nonspatial statistical methods, they incorporate space (proximity, area, connectivity, and/or other spatial relationships) directly into their mathematics. In addition, for those tools written with Python, the source code can be modified and extended in order to share these and other analysis tools with others. Besides GIS tools also widely implemented in open-source software, a number of special applications are dealing with space and time such as Web-based tools of US EIA, IEA, BP, and EEA. A list of selected Web-based tools for display of spatial and temporal data related to fossil fuels is shown in Table 4.16. Other applications have been created in the framework of research projects in the last years. As examples, FFDAS (Fossil Fuel Data Assimilation System) focused on estimates of carbon dioxide emissions is illustrated in Fig. 4.23, and monitoring of methane with satellites ENVISAT and GOSAT is shown in Fig. 4.24 (Table 4.17).

Table 4.15 A list of selected methods focused on space-time cluster analysis

Method	Description	Principal schema
Hot Spot Analysis (ArcGIS Pro)	Identifies statistically significant hot spots and cold spots using the Getis-Ord Gi* statistic by given a set of weighted features.	 http://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/hot-spot-analysis.htm
Cluster and Outlier Analysis (ArcGIS Pro)	Identifies statistically significant hot spots, cold spots, and spatial outliers using the Anselin Local Moran's I statistic by given a set of weighted features	 http://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/cluster-and-outlier-analysis-anselin-local-moran-s.htm
Emerging Hot Spot Analysis (ArcGIS Pro)	Identifies trends in the clustering of point densities (counts) or summary fields in a space-time cube created using the Create Space Time Cube tool. Categories include new, consecutive, intensifying, persistent, diminishing, sporadic, oscillating, and historical hot and cold spots.	 http://pro.arcgis.com/en/pro-app/tool-reference/space-time-pattern-mining/emerginghotspots.htm
Grouping Analysis (ArcGIS Pro)	Groups features based on feature attributes and optional spatial or temporal constraints.	 http://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/grouping-analysis.htm

4.6 Spatial and Temporal Modeling with GIS

Environmental models are used to be developed to understand spatial and temporal phenomena of environmental processes and to optimize their environmental impacts. In case of fossil fuels, these models can support impact assessment of extraction, treatment, transportation, and combustion together with environmental pollution and disturbance of landscape patterns. Recently, there have been several different contexts for the term modeling in the environmental sciences.

In the traditional environmental dynamic modeling, the models are used to be representations of processes that are believed to occur in the real world, mainly from the geosphere, the hydrosphere, and the atmosphere and also from the biosphere. Thus, the huge variety of phenomena and approaches can be studied in the

Table 4.16 A list of selected Web-based tools for display of spatial and temporal data related to fossil fuels

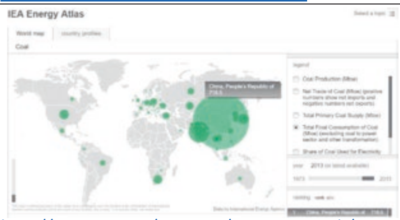
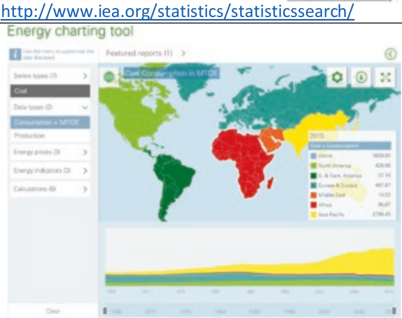
Organization	Description	Website
U.S. EIA (Energy Information Administration)	The EIA provides a wide range of information and data products covering energy production, stocks, demand, imports, exports, and prices. EIA also prepares analyses and special reports on topics of current interest. Mapping applications are focused on energy view of petroleum, natural gas, renewable energy power plants, coal, biomass, solar, geothermal, fossil fuel resources, energy infrastructure, electricity, wind and hydroelectric issues. Example: Mapping of petroleum production over the world ->	 http://www.eia.gov/beta/international/
IEA (International Energy Agency)	The IEA is made up of 29 member countries. The IEA examines the full spectrum of energy issues and advocates policies that will enhance the reliability, affordability and sustainability of energy in its 29 member countries and beyond. Example: Total final consumption of coal in 2013 ->	 http://www.iea.org/statistics/statisticssearch/
BP (British Petroleum)	The BP provides fuel for transportation, energy for heat and light, lubricants to keep engines moving and petrochemicals used to make everyday items. The BP energy charting tool allows to interrogate data, create charts and download reports from the Statistical Review of World Energy. Example: Consumption of coal in a few part of the world ->.	 http://www.class.ngdc.noaa.gov/saa/products/welcome
EEA (European Environment Agency of the European Union)	The EEA provides sound, independent information on the environment. The EEA is a major information source for those involved in developing, adopting, implementing and evaluating environmental policy, and also the general public. Example: a list of data products focused on environmental mapping ->.	 http://reverb.echo.nasa.gov/reverb/

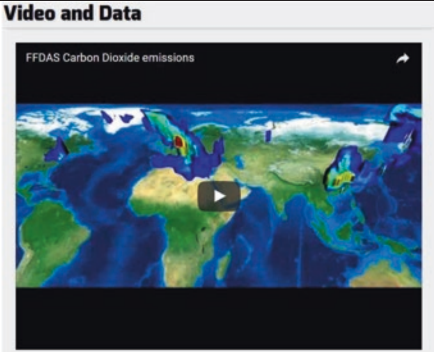
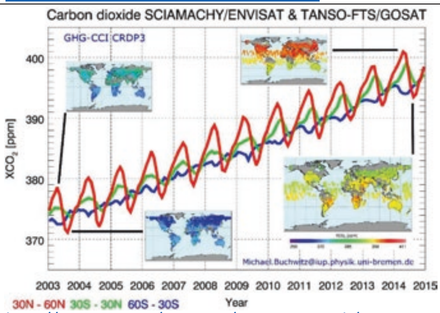
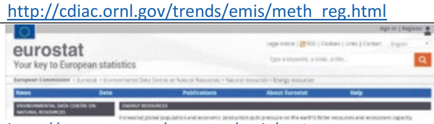
Fig. 4.23 Mapping the surface coal mine with 3D laser scanner HDS3000 (on the left side) and GPS (on the right side)

Fig. 4.24 Mapping the surface coal mine with 3D laser scanner HDS3000 (on the left side) and GPS (on the right side)

framework of environmental systems and their models. Dynamic modeling can be deterministic or stochastic in dependence on nature of the environmental processes that are described by physical, chemical, or biological laws and rules. It includes processes of diffusion, dispersion, advection, sorption, and other basic phenomena. There are models that can simulate global processes of the entire globe or local phenomena of the mass and energy transport. The description of the processes and phenomena is based on the mathematical approach, which deals with the changes of variables, such as pollutant concentration or species density, in space and time. Now, the solution of mathematical models can be made by computer programs that assist in time-consuming numerical calculations of multidimensional problems and spatial and temporal analysis of the results.

In spatial modeling by GISs, the models are considered as a template into which the spatial datasets needed for a particular application can be fitted. Thus, data models

Table 4.17 A list of applications created in the framework of research projects

Organization	Description	Website
FFDAS project (Fossil Fuel Data Assimilation System**)**	The subsets of the FFDAS include fossil fuel carbon dioxide emissions data focused on: - an electricity production sector - other sectors (all other fossil fuel, emissions excepting shipping and aviation), - EDGAR shipping – international and domestic shipping, - EDGAR aviation – international and domestic aviation, -uncertainty values associated with the total emissions. The FFDAS v2.0 visualization and data for download are available at FFDAS web pages ->	 http://hpcg.purdue.edu/FFDAS/index.php?page=media http://hpcg.purdue.edu/FFDAS/Map.php
GHG-CCI project (ESA)	Satellite observations (SCIAMACHY on ENVISAT in 2002 - 2012) and TANSO on GOSAT) combined with modelling help to improve our knowledge on carbon dioxide and methane sources and sinks as required for better climate prediction. GHG-CCI aims at delivering the high quality satellite retrievals needed for this application. Other satellite instruments will be used to provide constraints for upper layers such as IASI, MIPAS and ACE-FTS ->	 http://www.iea.org/statistics/statisticssearch/ http://www.esa-ghg-cci.org/?q=image_gallery
CDIAC (Carbon Dioxide Information Analysis Center)	CDIAC serves the climate change-related data and information needs of users worldwide. CDIAC includes estimates of carbon dioxide emissions from fossil-fuel consumption and land-use changes; records of atmospheric concentrations of carbon dioxide and other radiatively active trace gases and other related information ->.	 http://cdiac.ornl.gov/ http://cdiac.ornl.gov/trends/emis/meth_reg.html
EUROSTAT (European Commission)	Eurostat's task is to provide the European Union with statistics at European level that enable comparisons between countries and regions. GISCO (Geographic Information System of the Commission) can localize, analyze, visualize environmental data ->.	 http://ec.europa.eu/eurostat/web/main http://ec.europa.eu/eurostat/web/gisco/overview

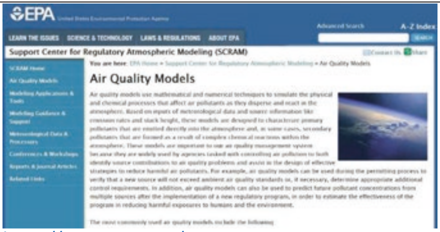
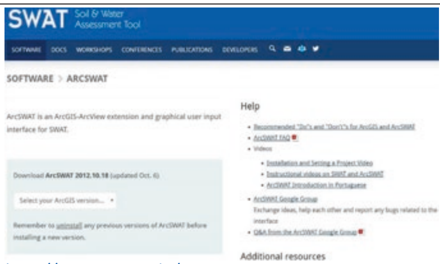
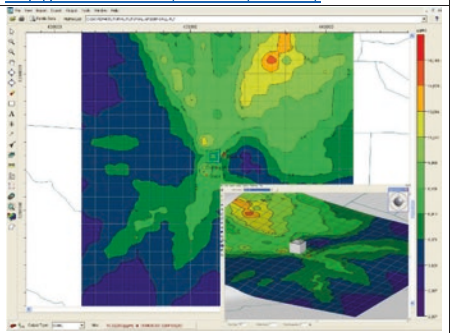
based on geodatabase design, mostly preferred for large datasets, can be also used for smaller data amounts. But the GIS data models implemented in the geodatabases share universal concepts that are important for data sharing and building of more complex spatial and temporal analyses. For example, land cover classes can be represented by polygons with their boundaries and share a geometry set of rules. Roads, railways, or rivers are represented by their centerlines, which are connected at the endpoints, and the topological connection in a geometric network enables tracing and interconnection based on a set of rules. In addition to the geometric representation, all these features have a commonly used set of attributes and relationships to tax their rolls. All datasets are used to be stored in the geodatabase that can manage spatial features and their topology together with the support of spatial and temporal model tasks such as landscape disturbance or environmental modeling. For example, risk assessment focused on environmental pollution can be supported by a number of geostatistical tools, such as exploratory spatial data analysis (ESDA), semivariogram modeling, threshold mapping, model validation and diagnostics, or surface prediction using cokriging.

In the framework of the both concepts, the models provide abstractions that simplify in communicating ideas from scientists to less scientifically informed public. The visual tools have become one of the most important ways of presenting environmental problems to a wide range of interests. Thus, GIS represents a powerful medium for communicating of spatial and temporal models in a wide variety of disciplines and from many different perspectives such as energy assessment of fossil fuels and their environmental impacts.

Complex monitoring systems and data management systems for large datasets are needed for development of environmental models that are used to support decision-making processes. The systematic assessment of environmental characteristics, such as air quality or climatic changes, based on regular measurements together with model predictions, can help to optimize living environment and improve public health. Considering to the huge amount of data, many studies, research reports, and other specific documents are published to inform research society and public about environmental problems. The impact assessment studies are mostly carried out by measurements in areas where the level of landscape disturbance and environmental pollution reaches the upper assessment thresholds.

A number of environmental datasets, analysis, and models are available on US EPA (Environmental Protection Agency) Web pages: https://www3.epa.gov/. Many environmental tools were created in the framework of research projects focused on environmental monitoring, analysis, and modeling. A number of modeling tools have been implemented in software packages, which offer user-friendly environment and advanced data management. These software tools also include data exchange methods, which support data formats managed by GIS and Web-based applications. A list of selected software tools for environmental management and impact assessment is shown in Table 4.18.

Table 4.18 A list of selected software tools for environmental management and impact assessment

Subject	Description	Website
U.S. EPA (Environmental Protection Agency)	The EPA's Air Quality Modeling Group (AQMG) conducts modeling analyses to support policy and regulatory decisions in the Office of Air and Radiation (OAR) and provides the full range of air quality models and other techniques used in assessing control strategies and source impacts. Documentation, guidelines, models and data are available on the website ->	 https://www3.epa.gov/ https://www3.epa.gov/ttn/scram/
USGS (U.S. Geological Survey)	The water resources Groundwater software and related material (data and documentation) are made available to be used in the public interest and the advancement of science. As an example, the MODFLOW (3D finite-difference groundwater model for prediction of groundwater conditions and interactions is selected for the website presentation ->	 https://www.usgs.gov/ http://water.usgs.gov/software/lists/groundwater
SWAT Soil and Water Assessment Tool, public domain model jointly developed by USDA ARS (Agricultural Research Service) and Texas A&M (AgriLife Research, a part of The Texas A&M University	It is a small watershed to river basin-scale model to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. It can be used for regional management in watersheds. As an example, ArcSWAT (ArcGIS-ArcView extension and graphical user input interface for SWAT) is selected for the website presentation ->	 http://swat.tamu.edu/ http://swat.tamu.edu/software/arcswat/
AERMOD View (Scientific Software Group)	It is a complete air dispersion modeling package which incorporates the U.S. EPA models into one interface: AERMOD, ISCST3 (Industrial Source Complex - Short Term), and ISC-PRIME (Industrial Source Complex - Plume RIse Model Enhancements). These models are used to assess pollution concentration and deposition from a wide variety of emission sources. AEROMOD is an air dispersion model designed for short-range dispersion of air pollutant emissions from stationary industrial sources ->	 http://www.scisoftware.com/environmental_software/ https://www3.epa.gov/ttn/scram/dispersionindex.htm

4.7 Case-Oriented Studies

Assessment of energy sources dealing with fossil fuels includes a wide range of operations. The attached examples are focused on environmental research using advanced computing tools such as mobile GIS, GPS, remote sensing data, and environmental modeling. Environmental research requires to manage a wide range of terrain measurements, remote sensing images, existing datasets, and inputs/outputs of mathematical models. Thus, GISs are often used to process datasets from terrain research, remote sensing, and a wide variety of other monitoring and modeling tools. In order to demonstrate the integration of spatial and temporal data together with methods related to spatial and dynamic modeling, a few case studies are presented for assessment of energy sources dealing with environmental research and risk assessment of opencast coal mining sites.

4.7.1 Using GPS and Mobile GIS for Mapping of Fossil Fuels in a Local Scale

An attached case study is focused on estimates of mineral dust impacts on the neighborhood of an opencast coal mine. Mapping of the potential emissions sources is complemented by measurements of wind flows with a few local meteorological stations. In the local scale, the wind flows are highly dependent on terrain morphology, which causes difficulties in estimating the dust transport. In addition to wind flows, physical processes in soils predetermine the conditions of primary dust dispersion. These processes are affected by variable natural factors, such as meteorology, soil state, and surface roughness. In cases of opencast coal mines, potential emission sources are temporary storage sites, coal sorting, excavators, conveyors, and moving vehicles. A temporary coal storage site with coal sorting excavators and erosion of slopes are illustrated in Fig. 4.23. Coal sorting causes dust emissions, which are spread by wind flows over an opencast mine and its neighbor areas. Erosion can form gullies that carry large volumes of water resulting in even greater erosion.

The GIS mapping of the mine is based on 3D surface laser scanning, GPS measurements, and existing digital thematic maps. The 3D laser scanners provided an efficient method for local 3D point cloud acquisition of the surface and its associated industrial installations. Complete coverage with point cloud data is created from multiple standpoints. Four scans with an average grid size of 0.2 m were performed with a Leica HDS 3000 3D laser scanner. While the 3D surface laser scanning was used for mapping of continuous parts, a few GPS instruments were used to assist in the capturing of breaklines of the slopes, boundaries of the temporary storage sites, and locations of other surface objects such as transport routes, potential emission sources, and the local meteorological stations. The accuracy of the GPS measurements was improved in the postprocessing phase using data from the nearest reference stations in the country. The final accuracy of the GPS spatial data after the postprocessing phase was 0.5 m. The 3D laser scanner Leica HDS3000 making point cloud acquisition and terrain data collection with GPS are shown in Fig. 4.24. The datasets created by laser scanning and GPS were imported into the GIS datasets in order to provide integrated data management, processing, analysis, and modeling. A part of the surface visualized by Leica Geosystems HDS Cyclone software is illustrated in Fig. 4.25a, which shows an overview of a slope visualized by merged 3D point clouds from the acquisition phase. A detailed view on a temporary coal storage site is shown in Fig. 4.25b. The 3D point cloud provides the detailed scan of the mining equipment with an average grid size of 0.2 m. Both the scans were created with a filtered and reduced data in order to optimize response time of the visualization functions.

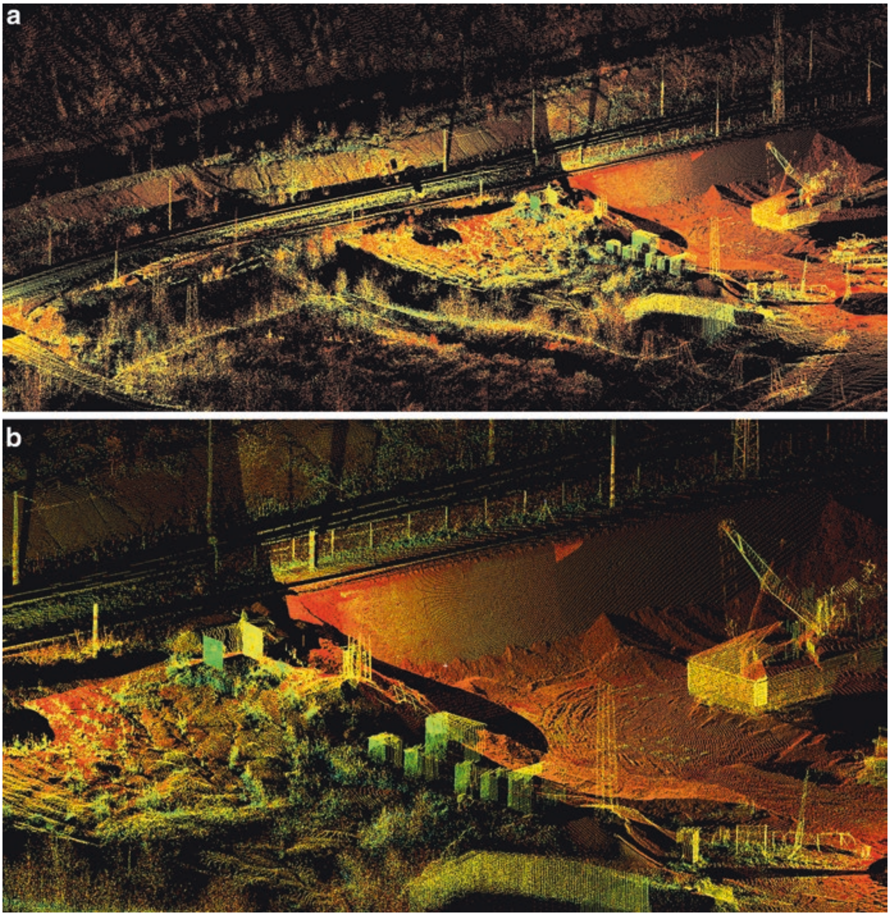


Fig. 4.25 (**a**) Visualization of a point cloud with the Leica Cyclone 3D point cloud processing software: an overview. (**b**) Visualization of a point cloud with the Leica Cyclone 3D point cloud processing software: a detail view

4.7.2 Mapping Surface Coal Mines in a Regional Scale with Landsat Images

A case study is focused on using the Landsat 8 image for environmental mapping of opencast mines, which are located in the Northwestern Czech Republic. The selected Landsat scene and an area of interest are illustrated in a map schema of Europe in Fig. 4.26. The area of interest in visible spectrum, thermal spectrum, and combination of visible and near infrared spectrum is shown in Figs. 4.27, 4.28 and 4.29, respectively.

The Landsat bands offer to explore surface by indexes. As an example, the normalized difference vegetation index (NDVI) is used to estimate the relative biomass. The chlorophyll absorption in red band and relatively high reflectance of vegetation in near infrared band can assist in estimating landscape disturbance by the opencast mine, Fig. 4.30. The NDVI shows the relative biomass by positive value and rocks and bare soil by values close to zero. The disturb landscape with mineral extraction sites and dump sites is shown in Fig. 4.31. The next image captured by Landsat 5 shows the opencast mines in 1988 (Fig. 4.32) and 2009 (Fig. 4.33), respectively. The seasonal changes in vegetation are illustrated by Landsat 8 images for spring season (Fig. 4.34) and autumn season (Fig. 4.35).

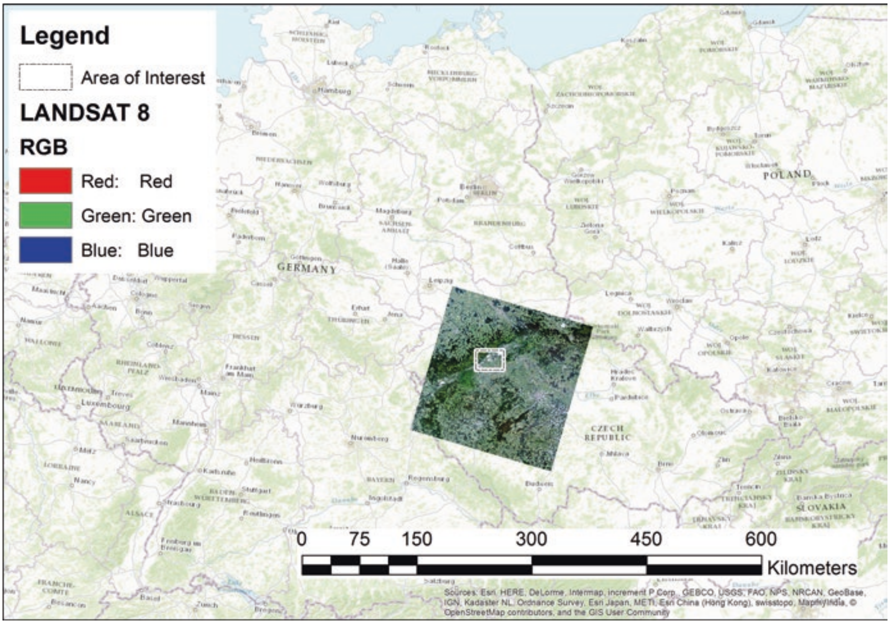


Fig. 4.26 The selected Landsat 8 scene (June 24, 2016) and an area of interest in the Northwestern Czech Republic

Fig. 4.27 Landsat 8 image (June 24, 2016) in visible spectrum (OLI band: 4, 3, 2), mines are indicated by light sites

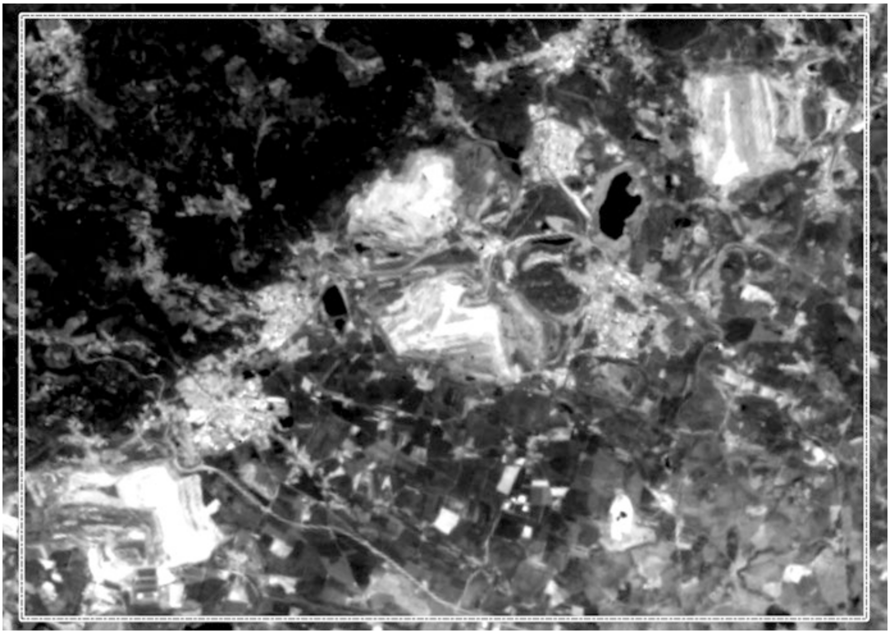


Fig. 4.28 Landsat 8 image (June 24, 2016) in thermal spectrum (TIRS: band 11), mines are indicated by light sites

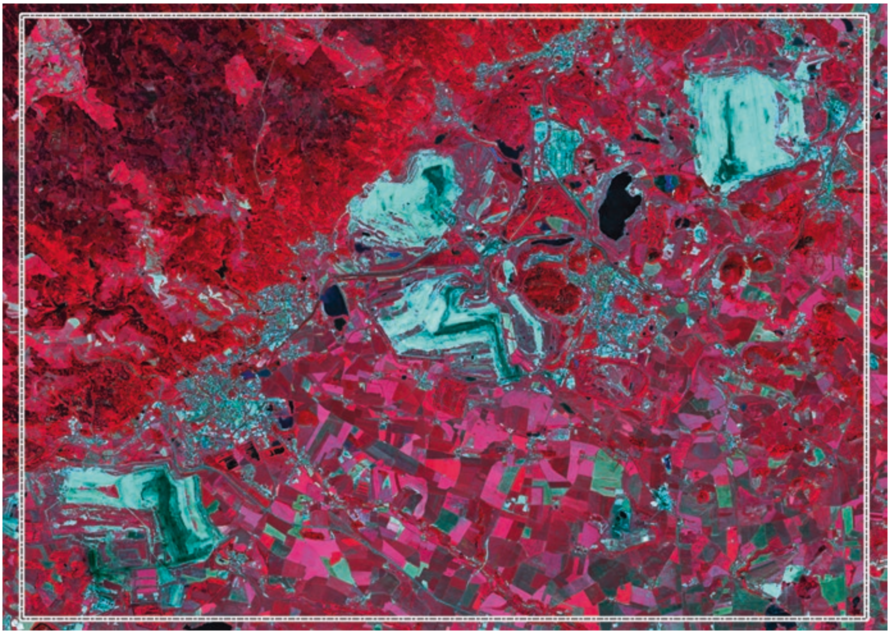


Fig. 4.29 Landsat 8 image (June 24, 2016) in visible and near infrared spectrum (OLI band: 5, 4, 3)

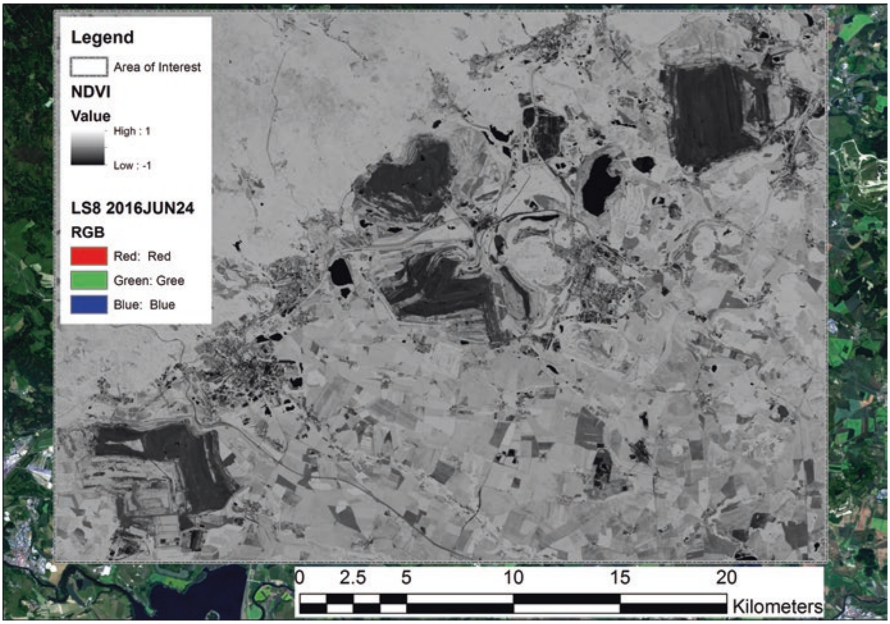


Fig. 4.30 NDVI (June 24, 2016): biomass is indicated by positive value and rocks and bare soil by values close to zero

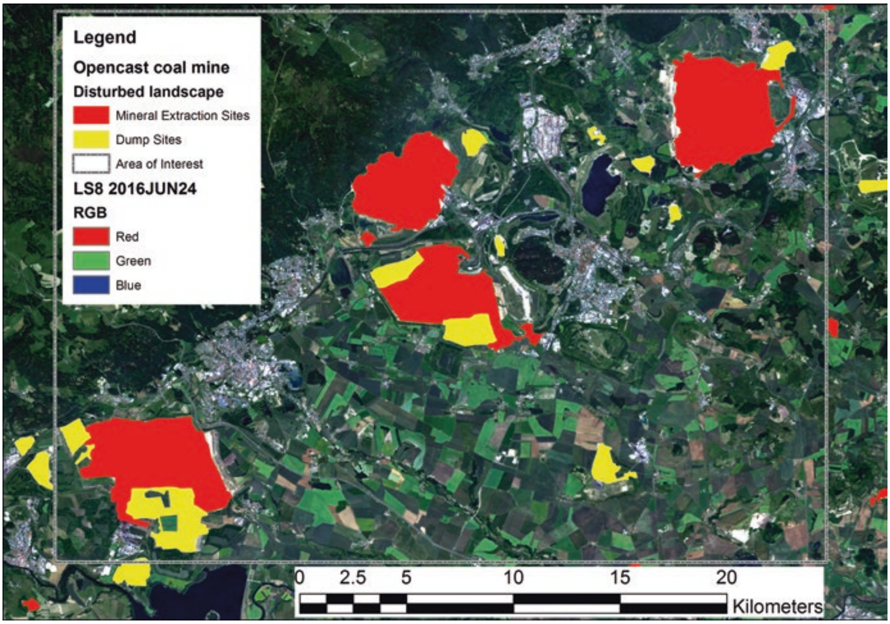


Fig. 4.31 The opencast coal mines: mineral extraction sites and dump sites (June 24, 2016)

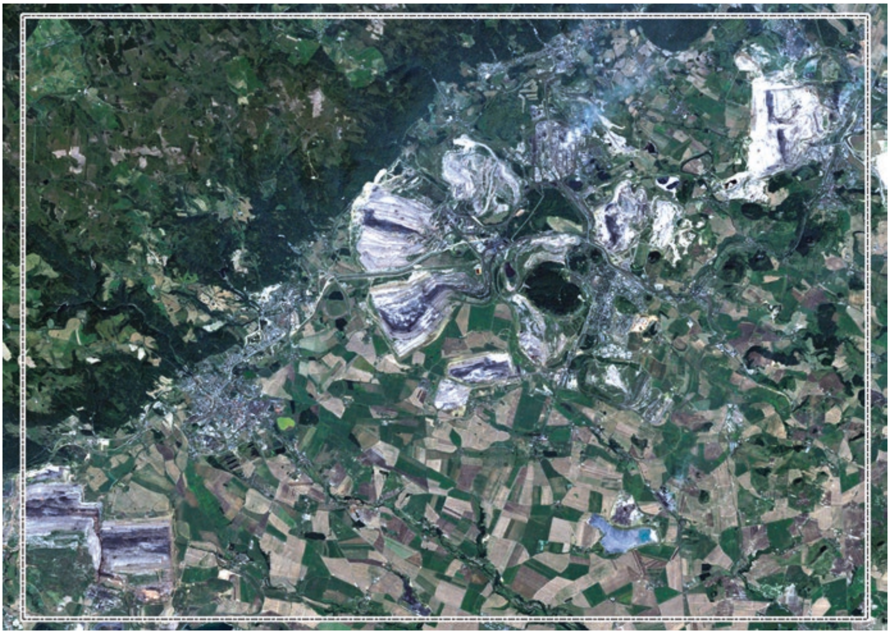


Fig. 4.32 Landsat 5 image (August 14, 1988, an initial image) in visible spectrum (TM band: 3, 2, 1)

Fig. 4.33 Landsat 5 image (August 24, 2009, an image captured after 21 years) in visible spectrum (TM band: 3, 2, 1)

Fig. 4.34 Landsat 8 image (March 18, 2015, spring season) in visible spectrum (OLI band: 3, 2, 1)

Fig. 4.35 Landsat 8 image (October 12, 2015, autumn season) in visible spectrum (OLI band: 3, 2, 1)

4.7.3 Modeling of Coal Dust Dispersion in a Local Scale

Estimates of dust dispersion can be provided either by measurements or by modeling, but it is often a combination of the both procedures, where model predictions are used to provide data for areas, in which monitoring data are lacking. Model predictions include a number of methods such as spatial interpolations, regression-based techniques, numerical modeling, and aerodynamic research in wind tunnels. Integration of data flows is seen as a central task for using of combined research. Complex processing of environmental data for spatial modeling, air dispersion numerical models, and aerodynamic research in wind tunnels include many steps, which are illustrated in Fig. 4.36.

The input datasets into the preprocessing phase include spatial data for the digital terrain model (DEM), emission sources for thematic maps dealing with location of emission sites and pollutant amounts, regular sampling of air pollution for validation of numerical models, and regular meteorological data (wind speed and direction and other variables such as temperature, humidity, precipitation, and solar). After the preprocessing stage, the created spatial and temporal datasets are integrated into the GIS and managed by the geodatabase, which can be complemented by other data, such as satellite images, aerial photographs, thematic maps, and historical records. These datasets are used by spatial modeling, air dispersion numeri-

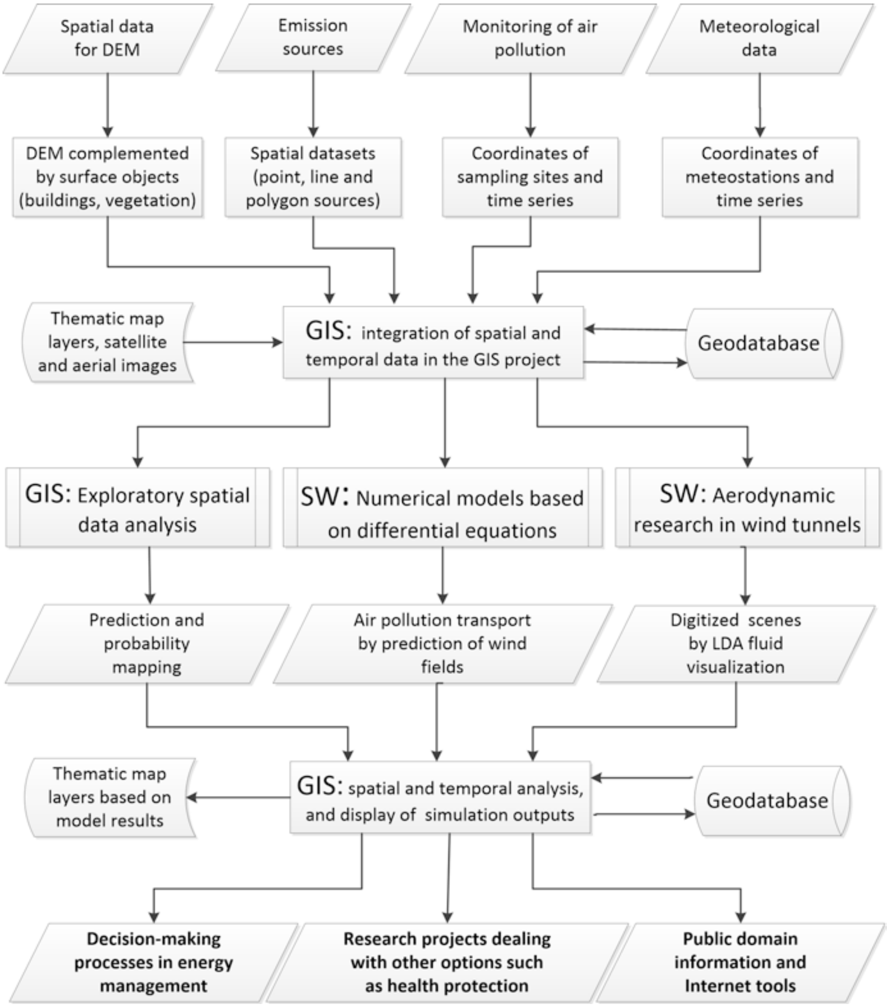


Fig. 4.36 Data flows in the processing of environmental data for spatial modeling, air dispersion numerical models, and aerodynamic research in wind tunnels designated for decision-making processes in energy management and related projects that are focused on health protection and information in the public domain

cal models, and aerodynamic research in wind tunnels to provide model predictions and validation and optimization of the explored processes in order to minimize health effects and other environmental risks. As an example a part of the DEM for numerical modeling and aerodynamic research is shown in Figs. 4.37 and 4.38. The DEM is complemented by localization of sites for monitoring of air pollution and collection of meteorological data. The standard color palette is used for symbolizing of various heights in altimetry of the opencast mine in the GIS environment.

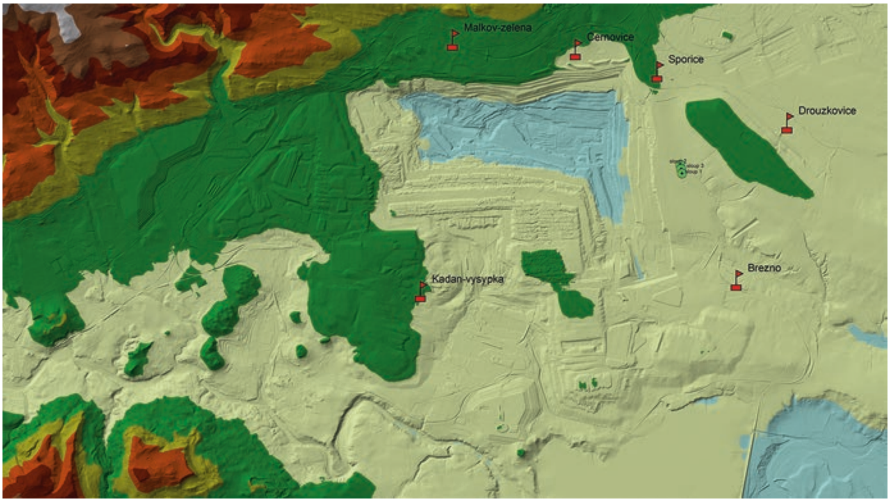


Fig. 4.37 Opencast coal mine: a part of the DEM in the GIS environment for numerical modeling and aerodynamic research complemented by localization of sites for monitoring of air pollution and regular collection of meteorological data (a predefined color palette is used for symbolizing of altimetry)

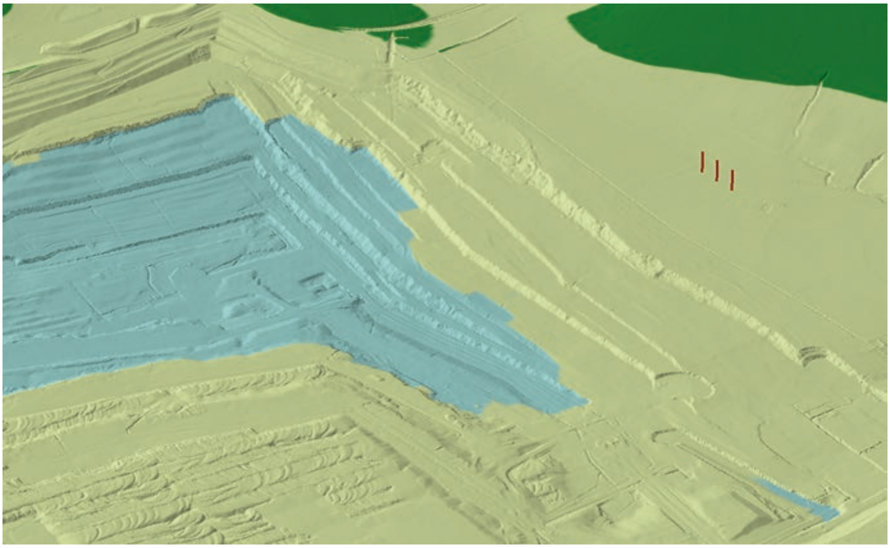


Fig. 4.38 Opencast coal mine: a 3D detail of the DEM in the GIS environment for numerical modeling and aerodynamic research complemented by localization of sites with three poles on the right site for monitoring of air pollution and collection of meteorological data (a predefined color palette is used for symbolizing of altimetry)

In case of dust dispersion, spatial modeling deals with deterministic and geostatistical interpolation methods, probability mapping, and geographically weighted regression (GWR). The interpolation and probability mapping are based on point samples. They are used for continuous surface layers that predict the values of air pollutant concentrations for every location in the area of interest. The probability maps can assess the probability that a critical concentration threshold value has been exceeded. GWR is used to provide a local model by fitting regression equations containing the dependent variable, concentration of air pollutant, and explanatory variables, such as potential sites of pollutant emissions, local wind speed, and surface temperature or humidity.

The numerical models based on the Navier-Stokes equations and other mathematical expressions are solved by standalone software tools, because GIS mostly supports only basic tasks in dispersion modeling. Additional procedures are needed to export data to the required data inputs of various numerical models. The initial tests were performed with Gaussian plume air dispersion models, such as AERMOD, ISCST3, and ISC-PRIME. The numerical models utilized data from the digital elevation model (DEM), extended by simplified 3D buildings, datasets containing air pollution sources and sampling points/receptors, as well as records of meteorological data. The output datasets are extracted and imported into the GIS by other software tools and GIS functions. These air dispersion numerical models employ hourly meteorological data records to define the conditions for plume rise, transport, diffusion, and deposition. The concentration or deposition values are estimated for each hour of input meteorology. The model outputs, user-selected, short-term averages of the concentrations at each receptor location, are exported into GIS for analysis and visualization, together with the existing spatial data, Fig. 4.39.

An alternative approach to numerical modeling is represented by aerodynamic research that uses wind tunnels to study the effects of air moving past models of a surface. The size of a model on a scale of about 1:9000 is 1.5 m x 1.5 m. The measurements are visualized by two-dimensional optical fiber laser Doppler anemometry (LDA). After capturing the scenes, the experimental data are imported into the computer system for other processing. The plastic models are produced using computer numerical control (CNC) machine tools. The data inputs are derived from DEMs created in GIS. The DEMs are based on a large dataset of points (1500 x 1500 points for the 1.5 m x 1.5 m model).

The inputs into the postprocessing phase represent continuous surface layers from spatial modeling, user-selected short-term averages of concentrations at each receptor location from numerical models and captured images of flow fields from aerodynamic research in wind tunnels. The postprocessing phase employs import of simulation results into the GIS project to integrate new datasets together with existing data in the geodatabase. The spatial and temporal analysis and visualization are used to create thematic maps of environmental impacts for decision-making processes, related research projects that are focused on health protection and information in the public domain. As an example of landscape disturbance, the changes in terrain heights in 2010–2014 are illustrated by a 3D view in Fig. 4.40, which compare two DEMs related to the stage of mining in 2010 and 2014. The difference of

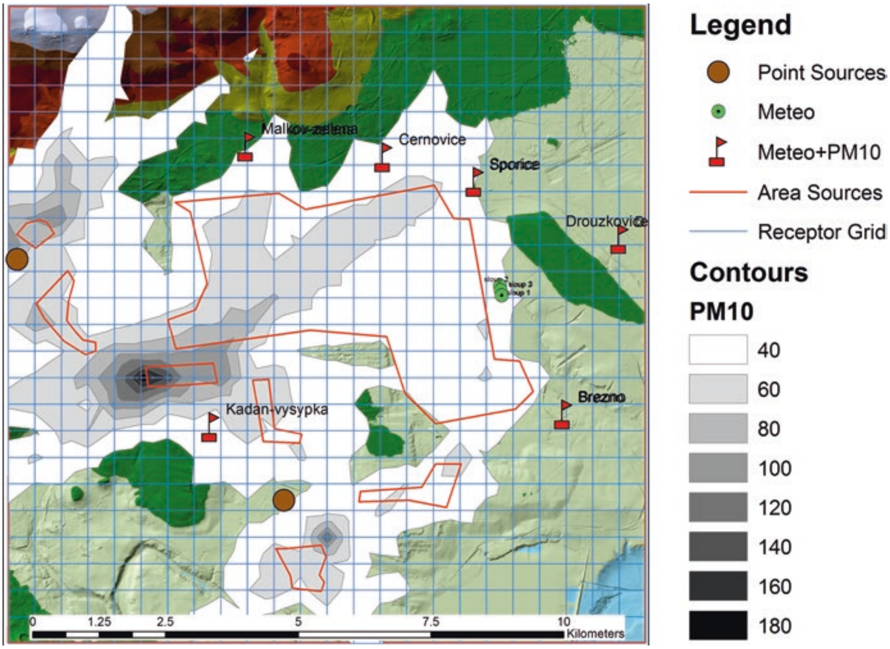


Fig. 4.39 The model outputs for a year period: user-selected short-term averages of concentrations at each receptor location in the regular grid. The isolines of PM_{10} concentrations are complemented by a DEM layer and by other features, such as monitoring stations and a receptor grid

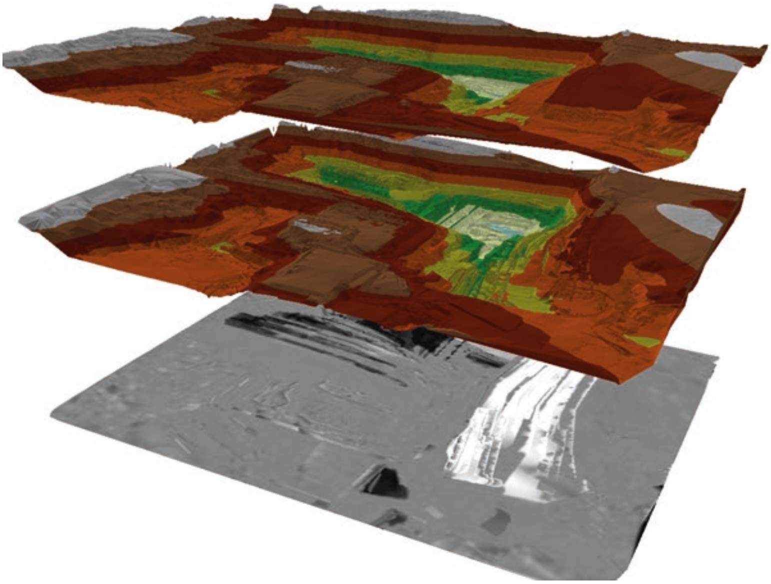


Fig. 4.40 A 3D view for visualization of the altimetry in the opencast mine in 2010–2014; the height difference on the surface of the mine between 2014 and 2010 is indicated with an attached layer by light pixels for decreasing by extraction and by gray pixels for increasing by accumulation

heights is indicated on the attached layer by light pixels for decreasing in elevations by extraction and by gray pixels for increasing in elevations by accumulation.

This case study focused on modeling of coal dust dispersion in a local scale in the GIS environment offers a wide range of spatial and temporal analyses. It is a way how to share data and methods dealing with spatial modeling, air dispersion modeling, and aerodynamic research in wind tunnels. Also it can explore the influence of terrain changes caused by mining activities on wind flows and air pollution dispersion, which is useful for decision-making processes related to reducing the environmental impacts of surface coal mining. The simulation of appropriate manmade barriers and different flow conditions enables to test the most suitable solution for reducing the environmental impacts of mining activities. The results can facilitate prediction of air pollution above the area of interest in the surface coal mine and its neighboring areas.

Bibliography

EIA. (2016). *International Energy Outlook 2016*. Retrieved from http://www.eia.gov/forecasts/ieo/pdf/0484(2016).pdf

IAEA. (2015). *Annual report 2014*. Retrieved from https://www.iaea.org/sites/default/files/gc59-7_en.pdf

IEA. (2015). *CO_2 emissions from fuel combustion highlights 2015*. Retrieved from http://www.iea.org/publications/freepublications/publication/CO2EmissionsFromFuelCombustionHighlights2015.pdf

IEA. (2016). *Coal information—2016 edition—Excerpt—Key coal trends*. Retrieved from http://www.iea.org/publications/freepublications/publication/KeyCoalTrends-1.pdf

IEA. (2016). *Oil information—2016 edition—Excerpt—Key oil trends*. Retrieved from http://www.iea.org/publications/freepublications/publication/KeyOilTrends.pdf

IEA. (2016). Natural gas information—2016 edition—Excerpt—Key natural gas trends. Retrieved from http://www.iea.org/publications/freepublications/publication/KeyNaturalGasTrends-1.pdf

IEA. (2016). *Tracking clean energy progress 2016*. Retrieved from https://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2016.pdf

IEA. (2016). *World energy statistics 2016*. Retrieved from http://www.iea.org/bookshop/723-World_Energy_Statistics_2016

IPCC. (2014). Climate change 2014: mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_full.pdf

Netherlands Environmental Assessment Agency. (2015). *Trends in global CO_2 emissions: 2015 report*. Retrieved from http://edgar.jrc.ec.europa.eu/news_docs/jrc-2015-trends-in-global-co2-emissions-2015-report-98184.pdf

Dictionaries and Encyclopedia

EIA. (2016). *Energy explained: Your guide to understanding energy*. Retrieved from http://www.eia.gov/energyexplained/index.cfm

Data Sources (Revised in January, 2016)

CLASS (NOAA). *Satellite imagery data sources*. Retrieved from http://www.class.ngdc.noaa.gov/saa/products/welcome

Digital Globe (Digital Globe). *Satellite imagery data sources*. Retrieved from http://www.digitalglobe.com/

Earth Explorer (USGS). *Satellite imagery data sources*. Retrieved from http://earthexplorer.usgs.gov/

EIA. *International Energy Statistics*. Retrieved from http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm

European Global Positioning System. Retrieved from http://gnss-centre.cz/en/

Mobile GIS. *ArcPad*. Retrieved from http://www.esri.com/software/arcgis/arcpad

Mobile GIS. *ArcGIS for Windows mobile*. Retrieved from http://www.esri.com/software/arcgis/arcgismobile

Mobile GIS. *Apps for smartphones and tablets*. Retrieved from http://www.esri.com/software/arcgis/arcgis-app-for-smartphones-and-tablets

Mobile GIS & GIS. *QGIS*. Retrieved from http://www.qgis.org/en/site/

Reverb (NASA). *Satellite imagery data sources*. Retrieved from http://reverb.echo.nasa.gov/reverb/

Sentinel Mission (ESA). *Satellite imagery data sources*. Retrieved from https://scihub.copernicus.eu/dhus/

USGS Landsat Global Archive. Retrieved from http://landsat.usgs.gov/USGSLandsatGlobalArchive.php

U.S. Global Positioning System. Retrieved from http://www.gps.gov/