

Table of Contents

- 1 Introduction and Structure 1**
 - 1.1 Energy system..... 1
 - MARTIN KALTSCHMITT
 - 1.1.1 Energy terms..... 2
 - 1.1.2 Energy consumption 4
 - 1.2 Applications of renewable energies 7
 - MARTIN KALTSCHMITT
 - 1.2.1 Renewable energies 7
 - 1.2.2 Investigated possibilities 9
 - 1.3 Structure and procedure..... 9
 - MARTIN KALTSCHMITT
 - 1.3.1 Principles 10
 - 1.3.2 Technical description..... 10
 - 1.3.3 Economic and environmental analysis 11
 - Definition of reference plants 11 (Heat provision 11, Electricity provision 12); Economic analysis 12; Environmental analysis 14
 - 1.4 Conventional energy provision systems 14
 - WOLFGANG STREICHER, MARTIN KALTSCHMITT
 - 1.4.1 Boundary conditions..... 14
 - 1.4.2 Power generation technologies..... 15
 - Economic analysis 15 (Investments and operation costs 17, Electricity generation costs 17); Environmental analysis 18
 - 1.4.3 Heat provision technologies 19
 - Economic analysis 19 (Investments and operation costs 21, Heat generation costs 22); Environmental analysis 22
- 2 Basics of Renewable Energy Supply 23**
 - 2.1 Energy balance of the earth 23
 - MARTIN KALTSCHMITT, ANDREAS WIESE
 - 2.1.1 Renewable energy sources 23
 - Solar energy 23; Geothermal energy 26; Energy from planetary gravitation and planetary motion 27
 - 2.1.2 Atmosphere 28
 - 2.1.3 Balance of energy flows 29

2.2	Solar radiation.....	32
	MARTIN KALTSCHMITT, WOLFGANG STREICHER	
2.2.1	Principles	32
	Optical windows 32; Weakening of radiation 32; Spectral range 33; Direct, diffuse and global radiation 34; Direct radiation on tilted, aligned surfaces 35; Diffuse radiation on tilted, aligned surfaces 37; Reflection radiation on tilted, aligned surfaces 38; Global radiation on tilted, aligned surfaces 38	
2.2.2	Supply characteristics.....	38
	Measuring radiation 38; Distribution of radiation 39; Time variations 40	
2.3	Wind energy	49
	MARTIN KALTSCHMITT, ANDREAS WIESE	
2.3.1	Principles	49
	Mechanisms 49; Global air circulation systems 51; Local air circulation systems 52; Influence of topography 55; Wind power 57	
2.3.2	Supply characteristics.....	57
	Measuring wind direction and wind speed 57; Wind distribution 58; Time variations 60; Frequency distribution 65	
2.4	Run-of-river and reservoir water supply.....	66
	MARTIN KALTSCHMITT, KLAUS JORDE	
2.4.1	Principles	67
	Water reserves of the earth 67; Water cycle 67; Precipitation 68; From precipitation to flow 69; Power and work capacity of water 71	
2.4.2	Supply characteristics.....	72
	Measuring water-technical parameters 72 (Measuring precipitation 72, Runoff measurement 72, Flow measurement 73); Distribution and variations of precipitation 74; River systems, runoff and runoff characteristic 77; Reservoirs 79	
2.5	Photosynthetically fixed energy.....	80
	IRIS LEWANDOWSKI	
2.5.1	Principles	81
	Structure and composition of plants 81; Photosynthesis 81; Influence of various growth factors 84 (Irradiation 84, Water 85, Temperature 85, Soil and nutrients 86, Plant cultivation measures 87)	
2.5.2	Supply characteristics.....	88
	Spatial supply characteristics 88; Temporal supply characteristics 89	
2.6	Geothermal energy.....	90
	ERNST HUENGES, MARTIN KALTSCHMITT	
2.6.1	Principles	90
	Structure of the earth 90; Temperature gradient 91; Heat content and distribution of sources 92; Terrestrial heat flow density 93; Heat balance at the surface of the earth 94; Geothermal systems and resources 95	
2.6.2	Supply characteristics.....	97
	Shallow underground 97; Deep underground 99	

3	Utilisation of Passive Solar Energy.....	103
	WOLFGANG STREICHER	
3.1	Principles	103
3.2	Technical description.....	104
3.2.1	Definitions	105
	Terms 105; Key figures 105 (Transmission coefficient 105, Secondary heat flow 105, Energy transmittance factor (g -value) 105, Diffuse energy transmittance factor (diffuse g -value) 106, Thermal transmittance coefficient (U -value) 106, Equivalent thermal transmittance coefficient (equivalent U -value) 106, Transmission losses 106)	
3.2.2	System components	107
	Transparent covers 107; Shading devices 110; Absorber and heat storage 113	
3.2.3	Functional systems	115
	Direct gain systems 115; Indirect gain systems 116 (Transparent thermal insulation 117, Solar systems with convective heat flow 119); Decoupled systems 119; Sunspaces 120	
4	Solar Thermal Heat Utilisation.....	123
4.1	Principles	123
	WOLFGANG STREICHER	
4.1.1	Absorption, emission and transmission	123
4.1.2	Optical features of absorbers.....	124
4.1.3	Optical features of covers.....	125
4.1.4	Energy balance	126
	General energy balance 126; Energy balance of the collector 126	
4.1.5	Efficiency and solar fractional savings.....	128
4.2	Technical description.....	129
	WOLFGANG STREICHER	
4.2.1	Collectors.....	130
	Collector components 130 (Absorber 130, Cover 131, Collector box 131, Other components 132); Installation 132; Collector designs and practical applications 132 (Non-concentrating swimming pool liquid-type collectors 133, Non-concentrating glazed flat-plate liquid-type collectors 133, Non-concentrating air collectors 135, Concentrating liquid-type or air collectors 135); Data and characteristic curves 136; Collector circuit 138	
4.2.2	Further system elements	139
	Heat store 139 (Liquid storage (Water storage) 139, Solid storage 141, Latent heat store 142, Duration of storage 143); Sensors and control systems 143; Heat transfer medium 145; Pipes 146; Heat exchanger 146; Pumps 147	
4.2.3	Energy conversion chain and losses	148
	Energy conversion chain 148; Losses 148	

4.2.4	System design concepts.....	149
	Systems without circulation 150; Open natural circulation systems 150; Closed natural circulation systems 150; Open forced circulation systems 151; Closed forced circulation systems 151	
4.2.5	Applications.....	152
	Solar heating of open-air swimming pools 152; Small systems 153 (DHW system with closed forced circulation 154, DHW systems with closed natural circulation 155, Solar combined systems (combisystems) 155); Solar-supported district heating systems 157; Further applications 159	
4.3	Economic and environmental analysis.....	160
	WOLFGANG STREICHER, MARTIN KALTSCHMITT	
4.3.1	Economic analysis.....	160
	Investments 162 (Collector 163; Storage 163; Other system components 163, Installation and operation 164, Total investments 164); Operation costs 165; Heat generation costs 166	
4.3.2	Environmental analysis	168
	Construction 168; Normal operation 169; Malfunction 169; End of operation 170	
5	Solar Thermal Power Plants	171
5.1	Principles	172
	GERHARD WEINREBE, WINFRIED ORTMANN	
5.1.1	Radiation concentration.....	172
5.1.2	Radiation absorption.....	176
5.1.3	High-temperature heat storage	177
5.1.4	Thermodynamic cycles.....	178
5.2	Solar tower power stations.....	181
	GERHARD WEINREBE	
5.2.1	Technical description.....	181
5.2.1.1	System components.....	181
	Heliostats 181 (Faceted heliostats 182, Membrane heliostats 183); Heliostat fields and tower 183; Receiver 184 (Water/steam receiver 184, Salt receiver 184, Open volumetric air receiver 185, Closed (pressurised) air receivers 186); Power plant cycles 187	
5.2.1.2	System concepts	187
	Solar One 187; Solar Two 188; Phoebus/TSA/Solair 189; PS10 189; Solar Tres 190; Solgate 190	
5.2.2	Economic and environmental analysis	190
	Economic analysis 190 (Investments 191, Operation costs 191, Electricity generation costs 192); Environmental analysis 192 (Construction 192, Normal operation 193, Malfunction 194, End of operation 194)	

5.3	Parabolic trough power plants	194
	GERHARD WEINREBE	
5.3.1	Technical description.....	195
5.3.1.1	System components.....	195
	Collectors 195 (Parabolic trough collectors 195, Fresnel collectors 196); Absorber/Heat Collecting Element (HCE) 197; Heat transfer medium 198; Collector fields 198	
5.3.1.2	Plant concepts.....	199
	SEGS plants 199; Integrated Solar Combined Cycle System (ISCCS) 201; Integration into conventional power plants 201	
5.3.2	Economic and environmental analysis	201
	Economic analysis 202 (Investments 202, Operation costs 202, Electricity generation costs 202); Environmental analysis 203	
5.4	Dish/Stirling systems	203
	DÖRTE LAING, GERHARD WEINREBE	
5.4.1	Technical description.....	204
5.4.1.1	System components.....	204
	Parabolic concentrator (dish) 204; Mounting structure 205; Solar tracking system 205; Receiver 205 (Tube receiver 206, Heat pipe receiver 206); Stirling motor 206	
5.4.1.2	Plant concepts.....	208
5.4.2	Economic and environmental analysis	210
	Economic analysis 210 (Investments 210, Operation costs 211, Electricity generation costs 211); Environmental analysis 212	
5.5	Solar updraft tower power plant	212
	GERHARD WEINREBE	
5.5.1	Technical description.....	216
5.5.1.1	System components.....	216
	Collector 216; Storage 217; Tower 217; Turbines 218	
5.5.1.2	Plant concepts.....	219
	Prototype located in the vicinity of Manzanares, Spain 219; Large solar updraft tower power plants 221	
5.5.2	Economic and environmental analysis	222
	Economic analysis 222 (Investments 223, Operation costs 223, Electricity generation costs 223); Environmental analysis 224	
5.6	Solar pond power plants	224
	GERHARD WEINREBE, MARTIN KALTSCHMITT	
5.6.1	Technical description.....	224
5.6.1.1	System components.....	224
	Pond collector 224; Heat exchangers 225; Thermal engine 226	
5.6.1.2	Plant concepts.....	226
5.6.2	Economic and environmental analysis	227
	Economic analysis 227 (Investment costs 227, Operation costs 228, Electricity generation costs 228); Environmental analysis 228	

6	Photovoltaic Power Generation	229
6.1	Principles.....	229
	MARTIN KALTSCHMITT, UWE RAU	
6.1.1	Energy gap model.....	229
6.1.2	Conductors, semiconductors and insulators	230
	Conductors 230; Insulators 231; Semiconductors 231	
6.1.3	Conduction mechanisms of semiconductors	231
	Intrinsic conductivity 231; Extrinsic conduction 232	
6.1.4	Photo effect.....	234
	External photo effect 234; Internal photo effect 235	
6.1.5	P-n-junction	235
6.1.6	Photovoltaic effect.....	237
6.2	Technical description.....	238
	DIRK UWE SAUER, UWE RAU, MARTIN KALTSCHMITT	
6.2.1	Photovoltaic cell and module	238
	Structure 238; Current-voltage characteristic and equivalent circuit 238; Efficiencies and losses 241; Cell types 244 (Solar cells from crystalline silicon 245, Thin-layer amorphous silicon (a-Si:H) solar cells 249, Thin film solar cells based on chalcogenides and chalcopyrites, particularly CdTe and CuInSe ₂ ("CIS") 251, Thin film solar cells made of crystalline silicon 254, Thin film solar cells with integrated serial circuit 254, Solar cells for concentrating photovoltaic systems 256, Dye solar cells made of nano-porous titan oxide (TiO ₂) 256); Solar module 258	
6.2.2	Further system components	260
	Inverters 260 (Island inverters 261, Grid-connected inverters 265); Mounting systems 269; Batteries and charge controllers 271; Further system components 277	
6.2.3	Grid-independent systems	277
	System concepts 278; Examples 280	
6.2.4	Grid-connected systems.....	283
6.2.5	Energy conversion chain, losses and characteristic power curve	284
	Energy conversion chain 284; Losses 285; characteristic Power curve 286	
6.3	Economic and environmental analysis.....	287
	MARTIN KALTSCHMITT, GERD SCHRÖDER, SVEN SCHNEIDER	
6.3.1	Economic analysis.....	287
	Investments 288; Operation costs 290; Electricity generation costs 290	
6.3.2	Environmental analysis	292
	Construction 292; Normal operation 293; Malfunction 293; End of operation 294	

7	Wind Power Generation	295
7.1	Principles	295
	KLAUS KEHL, MARTIN KALTSCHMITT, WOLFGANG STREICHER	
7.1.1	Idealised wind energy converter.....	296
7.1.2	Drag and lift principles	301
	Lift principle 301; Drag principle 306	
7.2	Technical description.....	308
	MARTIN KALTSCHMITT, MARTIN SKIBA, ANDREAS WIESE	
7.2.1	Wind turbine design	308
7.2.2	System elements	309
	Rotor 309 (Rotor blades 311, Rotor hub 312, Blade adjustment mechanism 312); Gearbox 313; Generator 314 (Synchronous generator 314, Asynchronous generator 315); Wind direction yaw mechanism 316; Tower 317; Foundations 318 (Gravity foundation 318, Monopile foundation 319, Tripod foundation 319); Grid connection 320; System aspects of offshore installation 321	
7.2.3	Energy conversion chain, losses and characteristic power curve	323
	Energy conversion chain 323; Losses 323; characteristic Power curve 325	
7.2.4	Power control	328
	Stall control 328; Pitch control 330	
7.2.5	Wind parks	331
	Wind park design 331; Grid connection 334	
7.2.6	Grid-independent applications.....	335
	Wind-battery systems 335; Wind pumps 336; Wind-diesel systems 337; Wind-sea water desalination 338	
7.3	Economic and environmental analysis.....	339
	MARTIN KALTSCHMITT, GERD SCHRÖDER, SVEN SCHNEIDER	
7.3.1	Economic analysis.....	339
	Investments 340; Operation costs 342; Electricity generation costs 342	
7.3.2	Environmental analysis	343
	Construction 343; Normal operation 344 (Audible sound 344, Infrasonic sounds 344, Disco effect 345, Shadow impact 345, Ice throw 345, Natural scenery 346, Preservation of bird-life 346, Further effects on fauna 347, Space consumption 347, Offshore wind power utilisation 347, Acceptance 347); Malfunction 347; End of operation 348	
8	Hydroelectric Power Generation	349
8.1	Principles	349
	KLAUS JORDE, MARTIN KALTSCHMITT	
	System setup 349; Intake 350; Penstock 351; Turbine 351; Outlet 352; Overall system 352	

8.2	Technical description.....	352
	KLAUS JORDE, MARTIN KALTSCHMITT	
8.2.1	Schematic layout	353
8.2.2	Categorisation and construction types.....	353
	Low-head plants 355 (Diversion-type plants 355, Run-of-river Plants 355); Medium-head plants 357; High-head Plants 355; Auxiliary plants 358	
8.2.3	System components	359
	Dam, weir or barrage 359; Reservoir 360; Intake 361; Headrace/ Penstock 361; Powerhouse 361; Turbines 361 (Kaplan, propeller, bulb, bevel gear, S and Straflo-turbines 363, Francis turbines 364, Pelton turbines 365, Cross-flow turbines 366, Water wheels 367); Outflow and tailrace 368; Shaft coupling and transmission 368; Generator 368; Transformer 369; Regulation 369	
8.2.4	Isolated and grid operation	369
8.2.5	Energy conversion chain, losses, and power curve	370
	Energy conversion chain 370; Losses 371; Operation behaviour and power curve 372	
8.3	Economic and environmental analysis.....	373
	MARTIN KALTSCHMITT, KLAUS JORDE	
8.3.1	Economic analysis	374
	Investments 375; Operation costs 376; Electricity generation costs 376	
8.3.2	Environmental analysis	378
	Construction 378; Normal operation 379 (Impoundments 379, Barrier effect of dam and power house 380, Diverted reaches 381); Malfunction 382; End of operation 383	
9	Utilisation of Ambient Air and Shallow Geothermal Energy	385
9.1	Principles	387
	WOLFGANG STREICHER, MARTIN KALTSCHMITT	
	Heat pump principle 388 (Compression heat pumps 388, Sorption heat pumps 389); Parameters 391 (Coefficient of performance (COP) 392, Work rate 393, Heate rate 393)	
9.2	Technical description.....	393
	BURKHARD SANNER, WOLFGANG STREICHER, MARTIN KALTSCHMITT	
9.2.1	Heat source systems for ambient air utilisation.....	394
9.2.2	Heat source systems for shallow geothermal energy utilisation	397
	Closed systems 398 (Horizontally installed ground-coupled heat exchangers 398, Vertically installed ground-coupled heat exchangers 400, Components with earth contract (energy piles, slot-die walls) 404); Open systems 405; Other Systems 406 (Coaxial wells 406, Cavity and tunnel water 407, Preheating/precooling of air 407)	

9.2.3	Heat pump	408
	Heat exchangers 408, Compressors 410; Expansion valves 411; Lubricants 412; Working media (refrigerants) 413	
9.2.4	Overall systems	415
	System configurations 415 (Heating systems with exhaust-air to inlet-air heat pump 415, Heating systems with ground-coupled heat pumps 416, Heat pump systems for heating and cooling purposes 417, Split system air conditioners for space heating and cooling 418); System aspects 420 (Types of operation 420, Areas of application 421, COP characteristics 423, Heat regime in near-surface ground 424)	
9.3	Economic and environmental analysis.....	425
	MARTIN KALTSCHMITT, GERD SCHRÖDER, WOLFGANG STREICHER	
9.3.1	Economic analysis.....	425
	Investments 427; Operation costs 429; Heat generation costs 430	
9.3.2	Environmental analysis	431
	Construction 432; Normal operation 432 (Environmental effects of heat pump working media 432, Thermal effects on the soil, the groundwater and the atmosphere 433, Hydraulic changes in the sub-soil caused by groundwater withdrawal 434, Noise effects 434, Effects caused by boreholes 434); Malfunction 434; End of operation 435	
10	Utilisation of Geothermal Energy.....	437
10.1	Heat supply by hydro-geothermal systems	437
	PETER SEIBT, FRANK KABUS, MARTIN KALTSCHMITT, STEPHANIE FRICK	
10.1.1	Technical description.....	437
	Geothermal well drilling 437 (Drilling technique 438, Well completion 440); Downhole part 442 (Well completion 442, Testing and modelling 443, Design of the downhole system 444); Uphole part 445 (Production of geothermal fluid 445, Quality assurance of re-injected water 447, Heat transfer 448, Corrosion prevention and suitable materials 449, Leakage monitoring 449, Slop system 450, Re-injection of geothermal fluid 450); District heating systems 450; Overall system layout 452	
10.1.2	Economic and environmental analysis	454
	Economic analysis 454 (Investments 456, Operation costs 457, Heat generation costs 457); Environmental analysis 460 (Construction 460, Normal operation 460, Malfunction 462, End of operation 462)	
10.2	Heat supply by deep wells.....	463
	MARTIN KALTSCHMITT, STEPHANIE FRICK	
10.2.1	Technical description.....	463

10.2.2 Economic and environmental analysis	466
Economic analysis 466 (Investment costs 466, Operation costs 466, Heat production costs 467); Environmental analysis 468 (Construction 468, Operation 468, Malfunction 469, Demolition 469)	
10.3 Geothermal power generation.....	469
REINHARD JUNG, FRANK KABUS, MARTIN KALTSCHMITT, STEPHANIE FRICK	
10.3.1 Technical description.....	474
10.3.1.1 Subsurface system	474
Exploitation schemes 474 (Geothermal fields 474, Hot water aquifers 475, Fault zones 475, Crystalline bedrock 476); Enhancing the productivity 478 (Acid treatment 478, Hydraulic fracturing 478, Waterfrac technique 479); Reservoir evaluation 480 (Borehole measurements 480, Seismic Fracture Mapping 481)	
10.3.1.2 Aboveground system.....	481
Open systems 482 (Direct steam utilisation 482, Single flash process without condensation 483, Single flash process with condensation 483, Double flash process with condensation 484); Closed systems 485 (Organic Rankine cycle 485, Kalina cycle 487); Combined systems 488	
10.3.2 Economic and environmental analysis	489
Economic analysis 489 (Investments 490, Operation costs 491, Energy generation costs 491); Environmental analysis 494 (Construction 494, Normal operation 494, Malfunction 495, End of operation 495)	

Annex A: Harnessing Ocean Energy 497

MARTIN KALTSCHMITT

A.1 Energy from wave motion	497
A.1.1 TAPCHAN system	498
A.1.2 OWC system.....	499
OWC buoy 500; OWC breaker-powered generator 500	
A.1.3 Further approaches	502
A.2 Energy from tides	503
A.2.1 Tidal power plants	503
A.2.2 Harnessing high and low tide streams	505
A.3 Further possibilities	506
A.3.1 Thermal gradients.....	506
A.3.2 Ocean currents	508
A.3.3 Salinity gradients.....	509
A.3.4 Water evaporation	510

Annex B: Energetic Use of Biomass	511
MARTIN KALTSCHMITT	
B.1 Structure of a typical supply chain	511
B.2 Conversion into final or useful energy	513
B.2.1 Thermo-chemical conversion	513
Gasification 514; Pyrolysis 514; Carbonisation 514	
B.2.2 Physical-chemical conversion	514
B.2.3 Bio-chemical conversion	515
Alcohol fermentation 515; Anaerobic digestion 515; Aerobic fermentation 515	
 Annex C: Energy Units	 517
 References.....	 519
 Index	 535