

Desert Rock Energy Co., PSD Appeal 08-03
Conservation Petitioners' Exhibits

EXHIBIT 45

DINE' CITIZENS AGAINST RUINING OUR ENVIRONMENT
 SAN JUAN CITIZENS ALLIANCE
 ENVIRONMENTAL DEFENSE FUND
 WESTERN RESOURCE ADVOCATES
 NATURAL RESOURCES DEFENSE COUNCIL
 SIERRA CLUB
 ENVIRONMENT COLORADO
 CLEAN AIR TASK FORCE
 GRAND CANYON TRUST

July 11, 2008

BY ELECTRONIC MAIL AND U.S. PRIORITY MAIL

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RE: Docket ID No. EPA-HQ-OGC-2008-0488, Comments on Consent Decree in Desert Rock Energy Co. v. U.S. EPA, No. 4:08-cv-872 (U.S. District Court, Southern District of Texas, Houston Division)

Dear Mr. Doster and others:

On June 3, 2008, the U.S. Environmental Protection Agency ("EPA") entered into a proposed Consent Decree with Desert Rock Energy Co., LLC and Dine Power Authority in the case of Desert Rock Energy Co. v. U.S. EPA, No. 4:08-cv-872 (U.S. District Court, Southern District of Texas, Houston Division). On June 11, 2008 EPA published notice of lodging of the proposed Consent Decree in the Federal Register. *See*, 73 Fed.Reg. 33087. The purpose of this letter is to provide written comments on the proposed Consent Decree by the undersigned organizations.

The proposed Consent Decree requires EPA to issue a decision on a PSD air permit application by July 31, 2008 for the proposed Desert Rock coal plant to be located on Navajo lands in northwestern New Mexico. The undersigned groups have previously provided written comments on the draft PSD permit issued by EPA on the following dates: November 13, 2006, October 4, 2007, March 4, 2008, April 18, 2008, April 24,

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2008, and June 17, 2008. The above-listed groups hereby incorporate by reference these previous letters into this comment letter.

For the reasons stated below, the undersigned groups request that the EPA and Department of Justice withdraw and/or withhold consent to the proposed consent decree because it is inappropriate, improper, inadequate, and/or inconsistent with the requirements of the Clean Air Act and the law in general.

DREC and DPA are not the real parties in interest and do not have standing

The PSD permit application at issue was originally submitted to EPA by Steag Power LLC. *See, PSD Permit application cover page dated May 2004 attached hereto.* In the Complaint in this matter, DREC and DPA state “EPA notified the permit applicant [Steag Power LLC] by letter dated May 21, 2004 that the permit application was complete.” *See, Complaint, p. 3, § 6 and Exhibit A to the Complaint.*

Steag Power LLC was subsequently acquired by Sithe Global Power LLC. On or about July 19, 2006, EPA Region 9 issued a draft PSD air permit. The draft permit was issued to the current owner and applicant of the proposed Desert Rock plant—Sithe Global Power, LLC. *See, EPA Public Notice of Draft Air Permit attached hereto.*

The EPA must withdraw and/or withhold consent to the proposed consent decree because the Plaintiffs in the lawsuit--Desert Rock Energy Co. LLC (“DREC”) and Dine Power Authority (“DPA”)--are not the permit applicant, are not the real parties in interest, and lack standing to bring its lawsuit. Sithe Global Power LLC and its predecessor Steag Power LLC are the permit applicant, not DREC and DPA. As evidence, EPA Region 9’s public notice of the draft permit and hearing state that the PSD permit was issued to “Sithe Global” not DREC or DPA. *See, EPA Public Notice of Draft Air Permit.* As such, DREC and DPA are not the real parties in interest with regard to the PSD permit application and are not entitled to the relief sought in the Consent Decree. Fed. R. Civ. Pro. 17(a)(1) (“Every action shall be prosecuted in the name of the real party in interest.”); *United States v. 936.71 Acres of Land*, 418 F.2d 551, 556 (5th Cir. 1969) (“‘The ‘real party in interest’ is the party who, by substantive law, possesses the right sought to be enforced, and not necessarily the person who will ultimately benefit from the recovery.’”) (citation omitted); *Lozano v. City of Hazelton*, 496 F.Supp.2d 477, 505 n. 27 (M.D. Pa. 2007) (“The requirement that an action be ‘prosecuted in the name of the real party in interest’ relates to attempts to ensure that those who have an interest in a legal action are actually represented in the case. This rule enshrines the principle that ‘the action must be brought by the person who, according to the governing substantive law, is entitled to enforce the right.’”) (citing 6A CHARLES ALAN WRIGHT, ARTHUR R. MILLER & MARY K. KANE, FEDERAL PRACTICE AND PROCEDURE § 1543 (2d. 1990)). Moreover, DREC and DPA lack standing both to bring the lawsuit and seek the relief sought in the consent decree. *Vt. Agency of Natural Res. v. U.S. ex rel Stevens*, 529 U.S. 765, 772 (2000) (“The Art. III judicial power exists only to redress or otherwise to protect against injury to the complaining party.”) (citing *Warth v. Seldin*, 422 U.S. 490, 499 (1975)); *Rogers v. Brockette*, 588 F.2d 1057, 1060 (5th Cir. 1979) (“[I]n order to sue in federal

court, a plaintiff must allege ‘a distinct and palpable injury’ to itself. . . . [O]rdinarily a plaintiff ‘must assert his own legal rights and interests, and cannot rest his claim to relief on the legal rights or interests of third parties.’”) (internal citations omitted). Since it may only grant the relief sought to the permit applicant, EPA must withdraw and/or withhold consent to the proposed consent decree.

Sithe’s notice letter fails to comply with mandatory preconditions to suit, and, therefore, the consent decree may not be entered and the case must be dismissed

Under the CAA Section 304, prior to bringing suit a party must provide 60 days advance notice of its intent to sue. The statute is absolute in requiring compliance with this obligation and EPA’s implementing regulations. *See*, 42 U.S.C. §7604(b)(1) (“Notice under this subsection *shall* be given in such manner as the Administrator *shall* prescribe by regulation.”)(emphasis added). On January 17, 2008 Sithe Global Power LLC notified EPA of its intent to sue. *See*, Exhibit B to Complaint. However, nowhere in the letter does it specifically state that Desert Rock Energy Co. LLC intended to sue EPA. More specifically, the notice letter states, “this letter shall serve as formal notice of Sithe’s intent to file suit against the U.S. Environmental Protection Agency”. *Id.* Although the notice letter mentions Desert Rock Energy Co. LLC as an “indirect wholly owned subsidiary of Sithe Global Power LLC” the letter gives no indication that DREC LLC would file suit against EPA. To the contrary, the notice letter states that only “Sithe” intended to sue EPA as the permit applicant. The notice letter defines the term “Sithe” as “Sithe Global Power LLC”. *Id.* Since Sithe Global Power LLC and Desert Rock Energy Company LLC are separate legal entities--separate limited liability companies—the notice letter must state that each of these legal entities intend to sue, not just Sithe Global Energy LLC.

Sithe’s January 17, 2008 notice letter also fails to comply with the requirements of the Clean Air Act regulations found at 40 C.F.R. § 54.3. These regulations state that the notice letter “shall state the full name and address of the person giving notice.” 40 C.F.R. § 54.3(a). Sithe’s January 17, 2008 fails to provide an address for either Sithe Global Power LLC or Desert Rock Energy Co. LLC. *See*, Exhibit B to Complaint. A party giving notice of intent to sue must strictly comply with the notice requirements. *Hallstrom v. Tillamook County*, 493 U.S. 20, 30–33 (1989) (dismissing suit for failure to strictly comply with notice requirements of Resource Conservation and Recovery Act even after decision on the merits reached). Failure to provide an address in a notice letter is a fatal flaw. *See id*; *Wash. Trout v. McCain Foods, Inc.*, 45 F.3d 1351, 1354 (9th Cir. 1995) (dismissing suit for lack of subject matter jurisdiction because notice letter failed to include address and phone number of named plaintiff or identity, address and phone number of potential plaintiffs). Strict compliance with notice requirements is a mandatory precondition to suit and a party’s failure to comply requires dismissal of its case. *Hallstrom*, 493 U.S. at 31; *Sierra Club v. Yeutter*, 926 F.2d 429, 437 (5th Cir. 1991); *Lockett v. EPA*, 319 F.3d 678, 682 (5th Cir. 2003); *Greene v. Reilly*, 956 F.2d 593 (6th Cir. 1993). Because Sithe’s notice letter fails to comply with mandatory

preconditions to suit, the court may not properly enter the consent decree and the case must be dismissed.

EPA should not issue the permit until the Deseret EAB case is decided

On August 30, 2007 U.S. EPA Region 8 issued a Prevention of Significant Deterioration (“PSD”) Permit to Construct (PSD-OU-0002-0.400) under the Clean Air Act (“CAA”) to Deseret Power Electric Cooperative for the construction of a new coal fired power plant near Bonanza, Utah. On October 1, 2007, the Sierra Club filed a Petition for Review and Request for Oral Argument with the EPA Environmental Appeals Board (“EAB”) challenging the Bonanza PSD permit (PSD Appeal 07-03). The EAB granted appeal on the issue of whether EPA erred by failing to require a Best Available Control Technology (“BACT”) limit for control of carbon dioxide emissions from the proposed Bonanza coal plant as required by Section 165 of the CAA, 42 U.S.C. §7475. The parties to the Bonanza EAB appeal have submitted their initial written briefing on this issue and oral argument before the EAB was held on May 29, 2008.

On June 16, 2008, subsequent to the oral argument, the EAB issued an Order requesting additional briefing from the EPA. More specifically, the EAB requested the following information:

Whether the carbon dioxide monitoring requirements springing out of or resulting in whole or in part from section 821 of Public Law 101-549, including but not limited to the requirements of 40 C.F.R. § 75.10(a)(3), are enforceable under the Clean Air Act. The brief shall identify the basis for the Region/OAR's position, and the relevance, if any, of the statement in section 821 that the provisions of section 412(e) of Title IV of the Clean Air Act shall apply for the purposes of section 821 “in the same manner and to the extent as such provision applies to the monitoring and data referred to” in section 412 of the Clean Air Act. The Region/OAR shall further identify any applicable law, other than the Clean Air Act, authorizing federal court jurisdiction and authorizing remedies or penalties for a violation of the CO₂ monitoring requirements. The Region/OAR shall identify whether and where this position, or any alternative position, as to the enforceability of section 821 under the Clean Air Act has been heretofore publicly articulated. The Region/OAR shall include within this identification the case name and number of every administrative or judicial enforcement action taken to date, if any, to enforce any requirements springing out of or resulting in whole or in part from section 821 of Public Law 101-549 or 40 C.F.R. part 75 (as they relate to CO₂) and the basis on which the jurisdiction of the court or Agency was invoked in each case. For purpose of understanding Congressional intent as to the scope of the permitting requirement or the PSD program (as opposed to the BACT requirement in particular), the Region/OAR shall address whether under section 165(a) of the Clean Air Act, 42 U.S.C. § 7475(a), a facility with the potential to emit at least the requisite number of tons per year, as specified in section 169(l) of the Clean Air Act, 42 U.S.C. § 7479(1), of carbon dioxide is a major emitting facility requiring a PSD permit. In this regard the Region/OAR

shall address the provision of the definition in section 169(1) defining a “major emitting facility” by reference to potential emissions of “any air pollutant” and the effect of the Supreme Court's decision in *Massachusetts v. EPA*, 127 S.Ct. 1438 (2007), confirming that carbon dioxide is an “air pollutant.” The Region/OAR's brief on this issue shall discuss among other things, the applicable regulatory history including the Agency's 2002 rulemaking and the Agency's statement in proposing the PSD regulations in 1977 that “[a]s required in the Act amendments, the proposed regulation will require a PSD preconstruction permit for any major stationary source if the source is a major stationary source of any pollutant regulated under the Act.”

See, EAB 2008 Order, pp. 3-4 attached hereto.

EPA's supplemental briefing on these issues is due to the EAB by July 16, 2008 and the other parties to the proceeding have a right to file a response brief by August 15, 2008. Thus, it appears that the EAB is poised to determine whether a BACT limit to control CO₂ is required in a preconstruction permit for new coal-fired power plants, such as Bonanza.

The settlement agreement with Desert Rock requires that by July 31, 2008 EPA must render a determination on the pending PSD permit application. Given the terms of this settlement agreement, EPA Region 9 will issue its decision on the Desert Rock PSD permit before the issues in the Bonanza EAB appeal are resolved.

Based on the recent developments in the Bonanza EAB appeal, the undersigned request that the EPA postpone any decision on Desert Rock permit until the EAB resolves these threshold issues raised in the Bonanza appeal. Global warming is the most vital issue of our time. Controlling carbon dioxide emissions is essential to mitigating climate change. Thus, the issues raised in the Bonanza appeal are of great importance to public health and the environment. Every new PSD permit issued for a coal-fired power plant, whether by EPA or a delegated state, will be impacted by the resolution of the Bonanza EAB appeal. The EAB essentially has primary jurisdiction over this issue and is poised to render a ruling. Issuance of the Desert Rock permit by Region 9 prior to a ruling in Bonanza would usurp the role of the EAB and force the parties to expend significant resources in appealing the Desert Rock permit without the benefit of a resolution of a central issue common to both proposed coal plants-whether carbon dioxide emissions must be controlled by a BACT emission limit.¹ As such, we request that EPA postpone issuing any decision on the Desert Rock PSD permit until at least 30 days after an EAB decision on the Bonanza appeal.

¹ Notably, only two weeks ago, a Georgia court ruled that CO₂ is “subject to regulation” under the CAA, and that Georgia's Environmental Protection Division was obligated to establish emission limitations for CO₂ in connection with a PSD permit for Dynegey's proposed Longleaf coal plant in Early County, Georgia. *See Friends of the Chattahoochee v. Couch*, Docket No. 2008CV146398 (Fulton County Super. Ct., June 30, 2008). The court's reasoning and application of law applies with equal force to EPA's obligation to address CO₂ from the proposed Desert Rock coal plant.

EPA Final Rule Lowering 8-Hour Ozone NAAQS

On March 27, 2008 EPA issued a Final Rule which lowers the 8-hour National Ambient Air Quality Standards (“NAAQS”) for ground level ozone from 0.08 ppm to 0.075 ppm. The Final Rule became effective on May 27, 2008.

The purpose of the March 27, 2008 Final Rule is “to provide increased protection for children and other ‘at risk’ populations against an array of O₃-related adverse health effects that range from decreased lung function and increased respiratory symptoms to serious indicators of respiratory morbidity including emergency department visits and hospital admissions for respiratory causes, and possibly cardiovascular-related morbidity as well as total nonaccidental and cardiorespiratory mortality.”

EPA’s lowering of the 8-hour ozone standard increases the risk that the standard will be violated in the future. In fact, the State of New Mexico has conducted preliminary air quality modeling and has concluded, “we will classify [San Juan] county as non-attainment which will limit development there.” *See, March 22, 2008 article on San Juan County ozone, attached hereto.* In fact, recent ozone monitoring data for San Juan County, New Mexico confirms that the new 8-hour ozone standard has been violated. *See, attached ozone monitoring data for San Juan County, New Mexico.*

To date, there has been no meaningful analysis of how the proposed Desert Rock coal plant may impact compliance with the recently lowered 8-hour ozone standard. However, Sithe admits that the Desert Rock coal plant will emit 3,325 tons per year (tpy) of NO_x and 166 tpy of Volatile Organic Compounds (VOCs). Given the significant emission of these ozone precursors, it is likely that construction and operation of the proposed Desert Rock coal plant will only exacerbate the 8-hour non-attainment ozone problems in the Four Corners region.

EPA cannot lawfully issue the PSD permit unless and until EPA is able to conclude, after conducting the required analysis, that emissions of ozone precursors from the proposed plant will not cause or contribute to violation of the recently lowered ozone NAAQs.

Final Decision on MACT for EGUs

Since our last comment letter on the Desert Rock PSD permit, the D.C. Circuit Court of Appeals has vacated EPA’s attempt to allow coal-fired power plants to avoid the Clean Air Act’s requirement that they apply maximum achievable controls for all the hazardous air pollutants (“HAPs”) they emit. As a result of the Court’s decision (discussed further below), and as we described in a March 4, 2008 letter to EPA, the Court’s ruling confirms that EPA has an obligation to ensure that the proposed Desert Rock facility complies with the requirements of section 112 of the CAA.

As a general matter, the CAA requires that EPA promulgate nationally-applicable regulations establishing, for each industry listed by the Agency, “emissions standards . . .

applicable to new and existing sources of hazardous air pollutants [that] require the maximum degree of reduction in emission” that the Administrator determines is achievable, CAA § 112(d)(2). For new sources in listed industries, these “maximum achievable control technology” (“MACT”) standards must be no less stringent than “the emission control that is achieved in practice by the best controlled similar source.” CAA § 112(d)(3); *see also Mossville Env’tl Action Now v. EPA*, 3790 F.3d 1232, 1235 (D.C. Cir. 2004) (affirming the CAA’s requirement that MACT emissions limits must be set for all HAPs emitted).

The Act further requires that EPA meet certain deadlines for promulgating MACT standards under section 112(d). *See, e.g.*, CAA § 112(c)(5), (c)(6), (c)(8), (e)(1), (e)(3). When EPA has failed to promulgate such standards, new sources (and modifications to existing sources) must demonstrate, before construction, and on a case-by-case basis, that they will meet MACT emissions limits. *See* CAA § 112(g)(2). In particular, Section 112(g)(2)(B) provides:

After the effective date of a permit program under subchapter V of this chapter in any State, no person may construct or reconstruct *any* major source of hazardous air pollutants, unless the Administrator (or the State) determines that the maximum achievable control technology emission limitation under this section for new sources will be met. Such determination shall be made on a case-by-case basis where no applicable emission limitations have been established by the Administrator.
42 U.S.C. 7412(g)(2)(B).

It is undeniable that EPA has failed to meet its obligation to promulgate MACT standards for new and existing EGUs. This failure is made clear in the recent opinion of the United States Court of Appeals for the D.C. Circuit. *New Jersey v. EPA*, 517 F.3d 574 (D.C. Cir. 2008), *mandate issued*, , Order, No. 05-1097 (Mar. 14, 2008), *reh’g and reh’g en banc denied*, Order, No. 05-1097 May 20, 2008

Specifically, in vacating EPA’s attempted removal of coal-fired power plants from the list of sources required to apply MACT, and also vacating the associated Clean Air Mercury Rule (“CAMR”), the Court concluded:

[I]n view of the plain text and structure of section 112, we grant the petitions and vacate the Delisting Rule. *See Allied-Signal, Inc. v. U.S. Nuclear Regulatory Comm’n*, 988 F.2d 146, 150-51 (D.C. Cir. 1993). This requires vacation of CAMR’s regulations for both new and existing EGUs. EPA promulgated the CAMR regulations for existing EGUs under section 111(d), but under EPA’s own interpretation of the section, it cannot be used to regulate sources listed under section 112; EPA thus concedes that if EGUs *remain listed under section 112, as we hold*, then the CAMR regulations for existing sources must fall. Resp’t Br. at 99, 101-02; *see also* Delisting Rule, 70 Fed. Reg. at 16,031.

517 F.3d at 583 (emphasis added). On March 14, 2008, the D.C. Circuit issued the Mandate in *New Jersey*, thereby making the ruling effective. Subsequently, on May 20, 2008, utility industry and EPA petitions for a rehearing by the D.C. Circuit 3-judge panel, and rehearing by the full Court *en banc* were denied.. As a result, the section 112(g)(2)(B) case-by-case MACT requirement must be satisfied before Desert Rock can begin construction. Not only have neither EPA nor the Navajo completed a case-by-case MACT determination for all the HAPs expected to be emitted by Desert Rock, there are no announced plans to do so. Moreover, EPA (or the Navajo) must provide an opportunity for notice and comment on the required Notice of MACT Approval, including the underlying analysis, prior to establishing final case-by-case MACT limits for Desert Rock.² 40 C.F.R. § 63.43(e)-(h).

We also pointed out in our March 4, 2008 letter that it is essential that the case-by-case MACT determination be issued in final form *before* any final PSD permit is issued. The reasons for this requirement are clear, as a MACT analysis and the obligations imposed on a proposed source in order to comply with MACT may have significant implications for the PSD analysis – requiring changes in equipment, fuel or fuel mix, facility configuration, operation and/or control technology, and having potentially important ancillary implications for other facility parameters (such as solid waste production, water use, emission control potential, etc.). This obligation to complete MACT review prior to issuance of a final PSD permit is also supported by the language and structure of the CAA.

Section 165(a) of the Act, a section of the Act dealing exclusively with PSD permitting, describes the basic obligations associated with of the issuance of a PSD permit.³ Among these provision is the following preclusion:

No major emitting facility . . . may be constructed in any area to which this part applies unless . . .

* * *

(3) the owner or operator of such facility demonstrates, as required pursuant to section 110(j) of the Act, that emissions from construction or operation of such facility will not cause, or contribute to, air pollution in excess of . . . (C) any other applicable emission standard or standards of performance under the Act.

² Indeed, in this instance it is unclear even how a MACT determination will be issued. EPA’s regulations provide for several mechanisms for issuing case-by-case 112(g) determinations (including pre-construction Title V permits), *see* 40 C.F.R. § 63.40 et seq.; however, any permitting authority must have appropriate legal authority to issue such a permit. While the Navajo have received a delegation of authority to administer a Part 71 Title V operating permits program, there is no mention of section 112 in this delegation agreement and it does not appear that the Navajo have received approval under section 112(l) to implement and enforce standards under section 112. Nor does it appear that any Navajo 112(g) program (including any Title V approach) has been certified as compliant (see EPA criteria at: <http://www.epa.gov/ttn/atw/112g/chklstg.pdf>). In any event, neither EPA nor the Navajo clearly indicated how and when a MACT determination will occur, or who will function as the permitting authority.

³ Section 165 is in Subchapter I, Part C of the Act, entitled “Prevention of Significant Deterioration of Air Quality.” The central function of this Part is to establish the regulatory requirements for PSD permitting and nonattainment new source review. *See* 42 U.S.C. § 7470 – 7492.

42 U.S.C. § 7475(a)(3).

Section 110(j), in turn, provides:

As a condition for issuance of any permit required under this subchapter, the owner or operator of each new or modified stationary source which is required to obtain such a permit must show to the satisfaction of the permitting authority that the technological system of continuous emission reduction which is to be used will enable such source to comply with the standards of performance which are to apply to such source and that the construction or modification and operation of such source will be in compliance with all other requirement of the Act.

42 U.S.C. §7410(j).

In this instance, EPA's section 112(g) regulations provide the specific and exclusive mechanism for demonstrating that "emissions from construction or operation of [a] facility will not cause, or contribute to, air pollution in excess of" any standard applicable to hazardous air pollutants under section 112, or demonstrating "that the technological system of continuous emission reduction which is to be used will enable such source to comply with the standards of performance which are to apply" under the section 112.⁴ Because that process has not occurred, the PSD permit may not properly issue.

The presence in the PSD provisions of this prohibition on constructing a new source without demonstrating that it will meet "any other applicable emissions standards" indicates that such demonstration should be a component of the overall PSD pre-construction approval process under section 165, and that such process should incorporate consideration of not just the PSD permitting requirements themselves, but all the various emission standards to which a unit would be subject.

Clearly, in this instance, there has been no coordination whatsoever between the PSD process and the case-by-case MACT determination. Indeed, it is not clear even that a pre-construction case-by-case MACT determination is planned. For those reasons, since it has not met its application obligations under CAA section 165(a), EPA and/or the Navajo Nation have failed to implement the requirements of section 112(g) and 165(a), and issuance of a PSD permit is therefore unreasonable, impermissible, and unlawful.

EPA has not completed consultation under Section 7 of the Endangered Species Act

Pursuant to Section 7 of the Endangered Species Act ("ESA"), 16 U.S.C. 1536, EPA must consult with the U.S. Fish and Wildlife Service ("FWS") to ensure that approval of the Desert Rock PSD permit does not jeopardize the continued existence of any threatened or endangered species or adversely modify any such species' critical

⁴ Just as the CAA's section 112(c)(9) provision provide the exclusive means for removing source categories from the Agency's section 112 source category list.

habitat. The consultation process should be complete before EPA issues a final PSD permit or makes its MACT determination. As EPA has acknowledged, the ESA serves an important function in protecting species and is relevant to the PSD permitting process. See *In re Indeck Elwood*, PSD Appeal 03-04, 13 E.A.D. ____ (EAB 2006). In *Indeck*, the Environmental Appeals Board (“EAB”) described the importance of the ESA this way:

The ESA, 16 U.S.C. §§ 1531-1544, was enacted in 1973 in response to increasing concerns about the impacts of human activities on fish, wildlife, and plants and their natural habitats. Endangered Species Act of 1973, Pub. L. 93-205, 81 Stat. 884 (1973) (codified at 16 U.S.C. §§ 1531-1544). Of particular concern were those species that had been rendered extinct or whose numbers were so depleted as to be in danger of or threatened with extinction. ESA § 2(a)(1)-(2), 16 U.S.C. § 1531(a)(1)-(2). Thus, one of the ESA’s primary purposes is “to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved, [and] to provide a program for the conservation of such endangered species and threatened species.” ESA § 2(b), 16 U.S.C. § 1531(b). In order to accomplish this goal, the ESA contains provisions for the “listing” of endangered or threatened species and the designation of critical habitat for those species by the Secretary of the Interior and the Secretary of Commerce In addition, the ESA imposes a number of specific substantive and procedural obligations on the activities of federal agencies, including EPA. See, e.g., ESA §§ 7(a)(1), (a)(2), 9(a)(1), (a)(2), 16 U.S.C. §§ 1536(a)(1), (a)(2), 1538(a)(1), (a)(2); see also 50 C.F.R. § 402.06(a) (noting both procedural and substantive requirements under the ESA).⁵

Section 7 of the ESA requires that the federal government consult with the appropriate agency within the Departments of Interior and Commerce regarding the potential effects on threatened or endangered species of any “agency action.”⁶ If there is likely to be *any* effect, a formal consultation or other action is required to ensure not adverse effects. In particular, section 7(a)(2), contains important substantive and procedural provisions which require, among other things, that:

Each Federal agency shall, in consultation with and with the assistance of the [FWS], *insure that any action authorized, funded, or carried out by such agency . . . is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat of such species which is determined by the [FWS] . . . to be critical*

⁵ *Indeck Elwood*, slip op. at 93.

⁶ As the EAB acknowledged, in the context of the ESA:

[A]gency “action” has been broadly defined by regulation to include “the granting of licenses, contracts, leases, easements, rights-of-way, [or] permits.” 50 C.F.R. § 402.02; see also *In re Dos Republicas Resources Co.*, 6 E.A.D. 643, 649 (EAB 1996) (noting that “[c]overed ESA Federal actions include the granting of a permit”); *Envil. Prot. Info. Ctr. (“EPIC”) v. Simpson Timber Co.*, 255 F.3d 1073, 1075 (9th Cir. 2001) (same). Section 7(a)(2), therefore, imposes a *substantive duty on federal agencies to ensure that none of their actions, including the issuance of a permit, is likely to jeopardize listed species or destroy or adversely modify such species’ critical habitat.* *Indeck Elwood*, slip op. at 94-95 (emphasis added).

ESA § 7(a)(2), 16 U.S.C. § 1536(a)(2) (emphasis added). In turn, ESA regulations provide as follows:

(a) Requirement for formal consultation. Each Federal agency shall review its actions at the earliest possible time to determine whether any action may affect listed species or critical habitat. If such a determination is made, formal consultation is required, except as noted in paragraph (b) of this section. The Director may request a Federal agency to enter into consultation if he identifies any action of that agency that may affect listed species or critical habitat and for which there has been no consultation. When such a request is made, the Director shall forward to the Federal agency a written explanation of the basis for the request.

(b) Exceptions. (1) A Federal agency need not initiate formal consultation if, as a result of the preparation of a biological assessment under § 402.12 or as a result of informal consultation with the Service under § 402.13, the Federal agency determines, with the written concurrence of the Director, that the proposed action is not likely to adversely affect any listed species or critical habitat. (2) A Federal agency need not initiate formal consultation if a preliminary biological opinion, issued after early consultation under § 402.11, is confirmed as the final biological opinion.

50 C.F.R. § 402.14.

As EPA has acknowledged, these obligations are both procedural and substantive, and they are specifically intended to *ensure* that any agency action (including the issuance of a PSD permit) will not adversely impact protected species or habitat. At the very heart of this obligation is the idea that the agency action must not occur *unless and until* a determination has been made that there will be no adverse affect on any protected species. And the agency should exercise its discretion to tailor any action it ultimately takes to avoid adverse impacts on species. These requirements are meaningless if the final action *precedes* the analysis necessary to determine if there will be any affect, what the affect will be, and what steps are required to prevent any adverse affects.

Indeed, ESA section 7 applies only where “there is discretionary Federal involvement or control.” 50 C.F.R. § 402.03; *see Nat’l Assn. of Home Builders v. Defenders of Wildlife*, 127 S. Ct. 2518, 2534-38 (2007). The purpose of the “discretion” requirement is to limit applicability of the consultation provision to those situation where the required consultation and analysis can actually influence the substantive outcome of the agency decision – i.e., where the agency has discretion to withhold or modify its decision so as to prevent or reduce adverse impacts on species. As the EAB explained:

The consultation procedures are intended to give the FWS the opportunity to determine whether the federal action is likely to jeopardize protected species or adversely impact critical habitat. ESA § 7(b)(3)(A); 16 U.S.C. § 1536(b)(3)(A). If such impacts are likely, the consultation process allows for identification of

reasonable and prudent alternatives to avoid such unfavorable impacts. *Id.*; 50 C.F.R. § 402.14(g)(5).

Indeck Elwood slip op. at 95 n.132.

This intent would be entirely undermined if an agency could take final action *prior* to completion of the analysis required to assess the full nature and extent of any affects. In fact, the ESA includes a requirement that once consultation has been initiated, an agency must refrain from “any irreversible or irretrievable commitment of resources” that would serve to foreclose the implementation of protective measures that might flow out of the consultation process. ESA § 7(d), 16 U.S.C. § 1536(d). Issuance of a final permit is an irreversible commitment of resources. As the EAB has explained, “the issuance of a final PSD permit would appear to be the point at which the permitting agency has irretrievably committed itself with respect to the discrete act of permitting a given activity. Accordingly, to avoid violating this requirement, the Agency should *complete* the ESA process prior to the issuance of the final permit.” *Indeck Elwood*, slip op. at 111 (emphasis added).⁷ Moreover, the EAB’s suggestion that a permit appeal, which incidentally extends the permit process, may somehow salvage a flawed process by giving the agency extra time to finish an incomplete consultation is bizarre. *See Indeck-Elwood*, slip op. at 112-13. The premise of this position – that the EPA’s illegal action is only impermissible if the agency gets caught and even then the agency gets another bite at the apple – turns the process on its head, prejudices the consultation process, and deprives the public of any meaningful opportunity to provide input on the permitting-related implications of the outcome of the consultation.

The Desert Rock permit will have tremendous impacts on ESA listed species, including, but not limited to, razorback sucker, Colorado pikeminnow, Mesa verde cactus, southwestern willow flycatcher, Mancos milkvetch, elkhorn and staghorn coral, and the newly listed polar bear.⁸ However, EPA has not consulted under Section 7.

⁷ Although the EAB did not find the permit in *Indeck Elwood* “legally defective” where consultation was completed after permit issuance and during the appeal period, the Board stated that it “would expect that ESA consultation would ordinarily be completed, at the very latest, prior to issuance of the permit and, optimally, prior to the comment period on the permit, where the flexibility to address ESA concerns is the greatest.” *Indeck Elwood* slip. op. at 95 n. 132 (emphasis added). As the EAB recognized, it is not an adequate “ESA compliance strategy” for the EPA to rely on an interested party filing an appeal to provide it time to complete ESA consultation. *Id.*

⁸ On May 14, 2008, the U.S. Department of Interior listed polar bears as a threatened species under the Endangered Species Act. The polar bear listing states, “the observed declines in the extent of Arctic sea ice are well documented, and more pronounced in the summer than in the winter. There is also evidence that the rate of sea ice decline is increasing. This decline in sea ice is of great importance to our determination regarding the status of the polar bear.” This decline in Arctic sea ice is attributable at least in part to global warming. As noted above, the Desert Rock coal plant will emit 12.7 million tons/year of carbon dioxide and over 635 million tons of the greenhouse gas over its expected 50-year lifetime. Emission of these greenhouse gases by the proposed Desert Rock power plant and its impacts on polar bears and other species should be considered prior to issuance of a final determination on Sithe’s permit application. Indeed, the listing of polar bears as a threatened species provides a new and compelling basis for EPA to perform a robust analysis and exercise its discretion to the fullest degree to address GHG emissions (especially CO₂)

Although EPA apparently intends to rely on the Bureau of Indian Affairs (“BIA”) consultation associated with BIA’s approval of a lease and rights-of-way associated with the Desert Rock coal plant, that process is not yet complete.⁹ Therefore, EPA has not factored endangered species protection into its decision or determined what actions are necessary to protect threatened and endangered species from jeopardy or adverse modification of their critical habitat. EPA’s failure violates Section 7 of the ESA.

Further, on January 7, 2008, the U.S. Fish and Wildlife Service (“F&W Service”) disagreed with BIA’s tentative determination that the Desert Rock plant may not adversely impact the endangered Colorado pikeminnow, razorback sucker, southwestern willow flycatcher. Instead, the F&W Service has concluded that the Desert Rock coal plant “may affect/is likely to adversely affect” these species. *See, F&W Service 1/7/08 letter attached hereto.* The F&W Service letter also indicates that important information has never been provided—such as coal composition/quality data, cumulative impact of the Desert Rock coal plant when combined with the San Juan and Four Corners coal plants, and the impacts on the hydrology of the area. *Id.*

EPA cannot issue a final PSD permit for construction of the proposed Desert Rock plant, or make a final MACT determination for the plant, before a biological opinion has been issued and the Fish and Wildlife Service has determined that the project will have no adverse impacts on listed species. EPA’s lack of initiation of formal consultation under the ESA precludes any meaningful analysis of impacts from issuance of the PSD permit or MACT determination.

Conclusion

In conclusion, for the reasons outlined above, the immediate issuance of the PSD permit for Desert Rock, as called for in the Consent Decree, would be both unlawful and imprudent. Accordingly, the undersigned request that the EPA and Department of Justice withdraw and/or withhold consent to the proposed consent decree because it is inappropriate, improper, inadequate, and/or inconsistent with the requirements of the Clean Air Act and the law in general.

under the PSD program’s provisions for establishing best available control technology, addressing collateral environmental impacts, and considering alternatives to the proposed projects. *See* CAA §§ 165(a)(2) and 169(3).

⁹ EPA’s designation of BIA as the “lead agency” for ESA consultation is inappropriate. Under the ESA regulations, factors relevant for determining the lead agency include “the time sequence in which the agencies would become involved, the magnitude of their respective involvement, and their relative expertise with respect to the environmental effects of the action.” 50 C.F.R. § 402.07. In this case, the time sequence favors EPA as the lead agency assuming EPA will issue the air permit prior to BIA’s completion of the NEPA process. Furthermore, EPA has considerably more expertise that is relevant for determining, with FWS, the impacts of air emissions on listed species.

Sincerely yours,

s/ Mike Eisenfeld

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ATTACHMENT 1

Application For Prevention of Significant Deterioration Permit For the Desert Rock Energy Facility



Prepared for:
Steag Power, LLC
Houston, TX



Prepared by:
ENSR Corporation

May 2004
Document Number 09417-360-250R1

ATTACHMENT 2

* * * PUBLIC NOTICE * * *

OF A PROPOSED CONSTRUCTION PERMIT
WHICH REGULATES THE EMISSION OF AIR POLLUTANTS
AND
OF A PUBLIC HEARING

PUBLIC NOTICE NO. AZP 04-01

On July 27, 2006 the Region 9 office of the United States Environmental Protection Agency (EPA) requested public comment on our proposal to issue a construction permit granting conditional approval, in accordance with 40 CFR 52.21, to Sithe Global Power for the construction and operation of a mine-mouth coal-fired power plant, to be located on the Navajo Indian reservation, approximately 25 miles southwest of Farmington, New Mexico. The project is known as the "Desert Rock Energy Facility" and is proposed to be located within the trust lands of the Navajo Nation. The power plant will be a supercritical pressure pulverized coal type and is designed for a total nominal generation capacity of 1500 MW (gross), consisting of two 750 MW units equipped with state-of-the-art emission controls. Coal will be delivered to the power plant via a fully enclosed above ground conveyor belt from the crushing facilities at the nearby BHP Billiton coal mine.

Because of the significant public interest in the proposed project, EPA will hold four Public Information Meetings. EPA staff will be present to answer questions and provide information regarding the PSD permitting process. The purpose of these meetings is not to receive or respond to formal comments.

Date:	Tues, Sept 12	Wed, Sept 13	Wed, Sept 13	Thurs, Sept 14
Time:	3:00 to 7:00 pm	9:30 am to 1:00 pm	4:00 to 8:00 pm	4:00 to 8:00 pm
Location	Navajo Nation Museum	Burnham Chapter House	Sanostee Veterans Memorial Building	Fort Lewis College
Address:	Highway 264 & Postal Loop Window Rock AZ	Burnham, NM	Sanostee Chapter Compound, Road N-34	Noble Hall, Room 130 Durango, CO

Pursuant to 40 CFR 124.12, EPA also will hold two Public Hearings to provide the public an opportunity to submit formal comments on the proposed permit. Any person may provide written or oral comments and data pertaining to the proposed permit at any of the Public Hearings. EPA will not respond to questions at the Public Hearings. EPA will respond to the formal comments received at the Public Hearings in a written document following the close of the public comment period on October 27, 2006.

Date:	October 3, 2006	October 4, 2006
Time:	Afternoon Session: 1:00 to 5:00 pm Evening Session: 6:00 to 9:00 pm	Afternoon Session: 1:00 to 5:00 pm Evening Session: 6:00 to 9:00 pm
Location:	Iron Horse Inn 5800 N. Main Ave. Durango, Colorado	Shiprock High School Auditorium Highway 64 West Shiprock, New Mexico

Copies of the proposed permit and other pertinent information are available for inspection and duplication during normal business hours at the following locations:

Navajo Nation EPA
Old NDR Building
Window Rock Blvd
Building #W088-090
Window Rock, Arizona 86515

Dine College Library
1228 Yucca Street
Shiprock, New Mexico 97420

These documents are also available on the EPA Region 9 website at:
<http://www.epa.gov/region09/air/permit/> or may be obtained by calling Robert Baker at (415) 972-3979, or by writing to:

Robert Baker (AIR-3)
EPA, Region 9
75 Hawthorne Street
San Francisco, CA 94105
Fax: (415) 947-3579
Email: desertrockairpermit@epa.gov

The Administrative Record for the proposed permit, which consists of the proposed permit, all data submitted by the applicant in support of the permit and additional documents relied upon to issue the proposed permit, is available for public inspection Monday through Friday from 9:00 A.M. until 4:00 P.M. in the Air Division of EPA (17th Floor), Region 9, 75 Hawthorne Street, San Francisco, California. Due to building security procedures, please call to arrange a visit 24 hours in advance. All public documents that are available in electronic form may be requested via email. Please contact Robert Baker for further information.

Comments on or objections to the proposed permit may be faxed, e-mailed, or delivered in writing to Robert Baker at the address shown above. Comments that are sent via fax or email or are hand-delivered must be received by October 27, 2006, and comments sent by regular mail must be postmarked by that date.

All comments will be included in the public docket without changes and may be made available to the public, including any personal information provided, unless the comment includes Confidential Business Information (CBI) or other information whose disclosure is restricted by statute. Information that you consider CBI or otherwise protected should be clearly identified as

such and should not be submitted through e-mail. If you send e-mail directly to EPA, your e-mail address will be automatically captured and included as part of the public comment. Please note that an e-mail or postal address must be provided with your comments if you wish to receive direct notification of EPA's final decision regarding the permit and its responses to the comments submitted during the public comment period.

A final decision to set the conditions of and issue a Final Permit, or to deny the application for a permit, shall be made after all comments have been considered. Notice of the final decision shall be sent to each person who has submitted written or oral comments or requested notice of the final permit decision. The decision will become effective 30 days from the date of issuance unless the decision is appealed to the Environmental Appeals Board pursuant to 40 CFR 124.19 (any person who submits written comments on the proposed permit or who participates in the Public Hearing may petition the Environmental Appeals Board to review any part of the permit decision within 30 days after the decision has been issued. Any person who failed to file comments and failed to participate in the Public Hearing on the proposed permit may petition for review by the Environmental Appeals Board only those parts of the final permit decision which are different than the proposed permit).

If this proposed permit becomes final, and there is no appeal, construction and operation of the facility identified above may begin subject to the conditions of the permit and other applicable permit and legal requirements.

Please bring this notice to the attention of all persons who you know would be interested in this matter.

Desert Rock Energy Co., PSD Appeal 08-03
Conservation Petitioners' Exhibits

EXHIBIT 46

**Cumulative SO2 Modeling Analyses of
Desert Rock Energy Facility and Other Sources at
PSD Class I Areas**

November 9, 2006

Prepared by:

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Principal

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<http://www.amiace.com>

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Appendix A - Output of Calpost for Scenario #1 (Zero Emissions from San Juan 1&2)

Appendix B - Output of Calpost for Scenario #2 (Emissions of 307.31 g/s from San Juan 1&2)

Appendix C - Output of Calpost for Scenario #3 (Zero Emissions from San Juan 1&2; Emissions of 1021.356 g/s from San Juan 3&4)

Appendix D - Output of Calpost for Scenario #4a (Emissions San Juan 1&2=192.402 g/s; San Juan 3&4=1021.356 g/s; Four Corners units=0)

Appendix E - Output of Calpost for Scenario #4b (Emissions San Juan 1&2=-93.114 g/s; San Juan 3&4=713.916 g/s; Four Corners units=0)

AMI Environmental has performed a cumulative modeling analysis of sulfur dioxide (SO₂) emissions emitted by the Desert Rock Energy Facility (DREF) and other cumulative sources. DREF is a 1500-MW coal-fired power plant that has been proposed in the Four Corners area by Sithe Global Power, LLC (Sithe). AMI Environmental (AMI) has been retained by Western Clean Energy Campaign to review and comment on the air quality and visibility impact analyses of the proposed facility. These analyses have been conducted for the Prevention of Significant Deterioration (PSD) Permit Application that has been submitted by Sithe to U.S. Environmental Protection Agency (EPA) Region 9 (see References in Section III below).

I. MODELING METHODOLOGIES

Model Selection

To be consistent with the results of the modeling analysis performed by ENSR Corporation on behalf of Sithe, the same versions of the Calpuff model and its supporting programs (Calmet for meteorological data, Postutil and Calpost for post-processing) of the PSD Application were used by AMI in the current modeling. These model executables along with the input files have been provided to AMI by EPA Region 9 as part of the Electronic Modeling Archive (see References in Section III below).

Meteorological Data

The Calpuff modeling used the meteorological data generated by the Calmet program from the 2001 and 2002 meteorological output of the mesoscale model MM5. These MM5 datasets have been used by ENSR in the PSD modeling. They have a grid resolution of 36 km (2001 data) and 12 km (2002 data). They have been provided to AMI by EPA Region 9 as part of the Electronic Modeling Archive (see References in Section III below). Using the MM5 data, the Calmet generated hourly three-dimensional windfields and other meteorological inputs on a 4-km grid for use by the Calpuff model.

Receptors

The Calpuff modeling predicts SO₂ concentrations at discrete receptors located at all 15 PSD Class I areas. These discrete receptors have been selected and recommended by the National Park Service for air quality and visibility modeling. The ENSR modeling used 3364 discrete receptors for 14 Class I areas, except Mesa Verde National Park. We have added 312 discrete receptors for Mesa Verde, for a total of 3676 discrete receptors.

II. EMISSIONS SCENARIOS AND MODELING RESULTS

The PSD modeling used the emissions and stack parameters of DREF and other cumulative sources shown in Table 4-11 (page 4-23) of the January 2006 Class I Area Modeling Update. The modeling performed by AMI used the same emissions and stack parameters except for the following differences:

1. Low-level emissions from DREF have also been modeled,
2. Emission Scenario #1 with zero emissions from San Juan Units 1 &2,
3. Emission Scenario # 2 with a combined emission rate of -307.31 g/s from San Juan 1 & 2,
4. Emissions Scenario #3 with zero emissions from San Juan 1& 2 and a combined emission rate of 1021.356 g/s from San Juan 3&4,
5. Emissions Scenario #4a with a combined emissions rate of 192.402 g/s from San Juan 1& 2, a combined emission rate of 1021.356 g/s from San Juan 3&4 and zero emissions from all Four Corners units, and
6. Emissions Scenario #4b with a combined emissions rate of -93.114 g/s from San Juan 1& 2, a combined emission rate of 713.916 g/s from San Juan 3&4 and zero emissions from all Four Corners units.

The PSD Permit Application modeling only considered the SO₂ emissions from the main boilers. In this modeling performed by AMI, the low-level emissions from the auxiliary boilers and other low-level sources (emergency diesel generators, firewater pumps) have also been modeled. An emission rate of 1.6823 g/s and stack parameters shown in Table 2-3 of the June 2006 Class II Area Modeling Update have been used in the modeling.

Five alternative emission scenarios were modeled for the San Juan generation station. Units 1 and 2 are expanding sources while Units 3 and 4 are consuming sources in the PSD modeling. In the first scenario, these expanding sources are assumed to have no emissions. In the second scenario, a combined emission rate of -307.31 g/s has been used (-154.2 g/s from San Juan Unit 1, and -153.11 g/s from San Juan Unit 2). This combined rate represents a 57% reduction of their original emissions of -722.069 g/s in the PSD modeling. In the third scenario, San Juan Units 1 &2 are assumed to have no emissions, and a combined emission rate of 1021.356 g/s has been used for the increment-consuming Units 3&4 (510.678 g/s from San Juan Unit 3, and 510.678 g/s from San Juan Unit 4).

Emissions Scenario #4a was modeled with a combined emissions rate of 192.402 g/s from San Juan 1& 2, a combined emission rate of 1021.356 g/s from San Juan 3&4 and zero emissions from all Four Corners units. Emissions Scenario #4b was modeled with a combined emissions rate of -93.114 g/s from San Juan 1& 2, a combined emission rate of 713.916 g/s from San Juan 3&4 and zero emissions from all Four Corners units.

Emissions scenarios 1 and 2 were modeled with the 2001 meteorological data. Modeling results are summarized in Table 1 below and outputs of the Calpost postprocessor are provided in Appendices A and B. This table shows that both short-term (3-hour and 24-hour) PSD Class I increments will be exceeded by the maximum concentrations (2nd high) predicted under both emissions scenarios for San Juan Units 1 and 2. Maximum concentrations of Scenario #1 are higher than those obtained under Scenario #2. These maximum concentrations were predicted by the Calpuff model to occur at the Mesa Verde National Park. This PSD Class I area is located about 80 km north of the DREF site. The annual-averaged maximum concentrations are well below the PSD Class I area increment of 2 ug/m³.

Table 1 – Maximum Cumulative SO₂ Concentrations (ug/m³) predicted by Calpuff at Mesa Verde NP under Two Emissions Scenarios for San Juan Units 1 & 2 (2001 Meteorological Data)

Averaging Period	Scenario #1 (No Emissions from San Juan Units 1&2)	Scenario #2 (Emissions -307.31 g/s from SJ Units 1 &2)	PSD Class I Increments (ug/m ³)
3-hour	49.732	34.669	25
24-hour	8.8556	5.9181	5
Annual	0.50944	0.38195	2

Emissions scenario #3 was modeled with the 2002 meteorological data. Modeling results are summarized in Table 2 below and the Calpost outputs are provided in Appendix C. This table shows that both short-term (3-hour and 24-hour) PSD Class I increments will be largely exceeded by the maximum concentrations (2nd high). The 3-hr increment will be exceeded by 260%, and the 24-hr increment by 240%. The maximum concentrations were predicted by the Calpuff model to occur at the Mesa Verde National Park (Receptor #3372 for 3-hr and Receptor #3376 for 24-hr). Table 2 also shows the contributions from DREF emissions to these maximum concentrations (1.21892 ug/m³ to the 3-hr concentration and 0.4530 ug/m³ to the 24-hr concentration). Thus, the DREF contributions are considered to be significant since they exceed the EPA-proposed significance levels (1 ug/m³ for 3-hr and 0.2 ug/m³ for 24-hr).

Table 2 – Maximum Cumulative SO₂ Concentrations (ug/m³) and DREF Contributions at Mesa Verde NP under Emissions Scenario #3 (Zero Emissions for San Juan 1&2; 1021.356 g/s for San Juan 3&4) (2002 Meteorological Data)

Averaging Period	Total Increment from DREF and cumulative sources	Contribution from DREF alone	PSD Class I Increments (ug/m ³)
3-hour	65.593	1.2192	25
24-hour	12.060	0.4530	5

Both emissions scenarios #4a and #4b were modeled with the 2002 meteorological data. Modeling results for Emission Scenario #4a are summarized in Table 3 below and the Calpost outputs are provided in Appendix D. This table shows that the 3-hour PSD Class I increment will be largely exceeded by the cumulative concentration (2nd high) by about 350%. This concentration was predicted by the Calpuff model to occur at the Mesa Verde National Park (Receptor #3371). Table 3 also shows the contribution from DREF emissions to this cumulative concentration (1.2533 ug/m³). Thus, the DREF contribution is considered to be significant since it exceeds the EPA-proposed significance level (1 ug/m³ for 3-hr).

Table 3 – Cumulative SO₂ Concentration (ug/m³) Exceeding the PSD Class I Increment with Significant DREF Contribution at Mesa Verde NP under Emissions Scenario #4a (192.402 g/s for San Juan 1&2; 1021.356 g/s for San Juan 3&4; zero emissions for Four Corners Units) (2002 Meteorological Data)

Averaging Period	Total Increment from DREF and cumulative sources	Contribution from DREF alone	PSD Class I Increment (ug/m ³)
3-hour	86.978	1.2533	25

Modeling results for Emission Scenario #4b are summarized in Table 4 below and the Calpost outputs are provided in Appendix E. This table shows that the 24-hour PSD Class I increment will be exceeded by the cumulative concentration (2nd high) by about 70%. This concentration was predicted by the Calpuff model to occur at the Mesa Verde National Park (Receptor #3371). Table 4 also shows the contribution from DREF emissions to this cumulative concentration (0.43058 ug/m³). Thus, the DREF contribution is considered to be significant since it exceeds the EPA-proposed significance level (0.2 ug/m³ for 24-hr).

Table 4 – Cumulative SO₂ Concentration (ug/m³) Exceeding the PSD Class I Increment with Significant DREF Contribution at Mesa Verde NP under Emissions Scenario #4b (-93.114 g/s for San Juan 1&2; 713.916 g/s for San Juan 3&4; zero emissions for Four Corners Units) (2002 Meteorological Data)

Averaging Period	Total Increment from DREF and cumulative sources	Contribution from DREF alone	PSD Class I Increment (ug/m ³)
24-hour	8.5284	0.43058	5

III. REFERENCES

Sithe Global Power/ENSR Documents

Application for Prevention of Significant Deterioration Permit for the Desert Rock Energy Facility. Prepared for Steag Power LLC by ENSR Corporation, ENSR Document No. 09417-360-250R1, May 2004 (hereinafter referred to as *May 2004 PSD Permit Application*).

Application for Prevention of Significant Deterioration Permit for the Desert Rock Energy Facility. Prepared for Steag Power LLC by ENSR Corporation, ENSR Document February 2004 (hereinafter referred to as *February 2004 PSD Permit Application*).

Desert Rock Energy Facility Application for Prevention of Significant Deterioration Permit – Class I Area Modeling Update. Prepared for Sithe Global Power LLC by ENSR Corporation, ENSR Document No. 10784-001-0004, January 2006 (hereinafter referred to as *January 2006 Class I Area Modeling Update*).

Desert Rock Energy Facility: Class I Area Modeling Supplement. Prepared for Sithe Global Power LLC by ENSR Corporation, ENSR Document No. 10784-001-0004, March 2006 (hereinafter referred to as *March 2006 Class I Area Modeling Supplement*).

Desert Rock Energy Facility Application for Prevention of Significant Deterioration Permit – Class II Area Modeling Update. Prepared for Sithe Global Power LLC by ENSR Corporation, ENSR Document No. 10784-001-0004b, June 2006 (hereinafter referred to as *June 2006 Class II Area Modeling Update*).

Electronic Modeling Archive

Copies of the modeling inputs and some outputs of the Calpuff modeling have been provided by EPA Region 9 to AMI on CD-ROM . EPA Region 9 has also provided the meteorological data for the years 2001 and 2002 on DVD.

Desert Rock Energy Co., PSD Appeal 08-03
Conservation Petitioners' Exhibits

EXHIBIT 47

IN THE UNITED STATES DISTRICT COURT
FOR THE SOUTHERN DISTRICT OF TEXAS
HOUSTON DIVISION

DESERT ROCK ENERGY COMPANY, LLC,)
)
and)
)
THE DINE POWER AUTHORITY,)
)
Plaintiffs,)
)
v.)
)
U.S. ENVIRONMENTAL PROTECTION)
AGENCY,)
)
and)
)
STEPHEN L. JOHNSON,)
)
Defendants.)

Civil Action No. 4:08-cv-00872

**MOTION TO INTERVENE OF DINE CARE, ENVIRONMENTAL DEFENSE FUND,
NATURAL RESOURCES DEFENSE COUNCIL, SAN JUAN CITIZENS ALLIANCE,
AND SIERRA CLUB**

Diné Care, Environmental Defense Fund, Natural Resources Defense Council, San Juan Citizens Alliance, and Sierra Club (collectively "Conservation Defendants") hereby move to intervene as of right in this action pursuant to Fed. R. Civ. P. 24(a)(2). In the alternative, Conservation Defendants move for permissive intervention in this action pursuant to Fed. R. Civ. P. 24(b)(2). In support of this motion, Conservation Defendants submit a supporting memorandum, and Affidavits of Dailan J. Long, Edward Mossimann, and Denise Fort. Attached to this motion as Exhibit A is Conservation Defendants' proposed Motion to Dismiss. Counsel for Prospective Intervenor-Defendants contacted counsel for Plaintiffs Desert Rock Energy Company, LLC and Diné Power Authority and were advised that they oppose this Motion.

Counsel for Prospective Intervenor-Defendants also conferred with counsel for the United States but have not yet been advised of the position that the United States will take on the motion.

Respectfully Submitted,

/s/ John M. Quinlan

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CERTIFICATE OF SERVICE

I hereby certify that on this 11th day of July 2008, I electronically filed the foregoing with the Clerk of the Court using the CM/ECF system which will send notification of such filing to the following e-mail addresses:

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/s/ John M. Quinlan

Desert Rock Energy Co., PSD Appeal 08-03
Conservation Petitioners' Exhibits

EXHIBIT 48

Climate Change 2007: Synthesis Report

Synthesis Report

An Assessment of the Intergovernmental Panel on Climate Change

This underlying report, adopted section by section at IPCC Plenary XXVII (Valencia, Spain, 12-17 November 2007), represents the formally agreed statement of the IPCC concerning key findings and uncertainties contained in the Working Group contributions to the Fourth Assessment Report.

Based on a draft prepared by:

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Introduction

Introduction

This Synthesis Report is based on the assessment carried out by the three Working Groups (WGs) of the Intergovernmental Panel on Climate Change (IPCC). It provides an integrated view of climate change as the final part of the IPCC's Fourth Assessment Report (AR4).

Topic 1 summarises observed changes in climate and their effects on natural and human systems, regardless of their causes, while Topic 2 assesses the causes of the observed changes. Topic 3 presents projections of future climate change and related impacts under different scenarios.

Topic 4 discusses adaptation and mitigation options over the next few decades and their interactions with sustainable develop-

ment. Topic 5 assesses the relationship between adaptation and mitigation on a more conceptual basis and takes a longer-term perspective. Topic 6 summarises the major robust findings and remaining key uncertainties in this assessment.

A schematic framework representing anthropogenic drivers, impacts of and responses to climate change, and their linkages, is shown in Figure I.1. At the time of the Third Assessment Report (TAR) in 2001, information was mainly available to describe the linkages clockwise, i.e. to derive climatic changes and impacts from socio-economic information and emissions. With increased understanding of these linkages, it is now possible to assess the linkages also counterclockwise, i.e. to evaluate possible development pathways and global emissions constraints that would reduce the risk of future impacts that society may wish to avoid.

Schematic framework of anthropogenic climate change drivers, impacts and responses

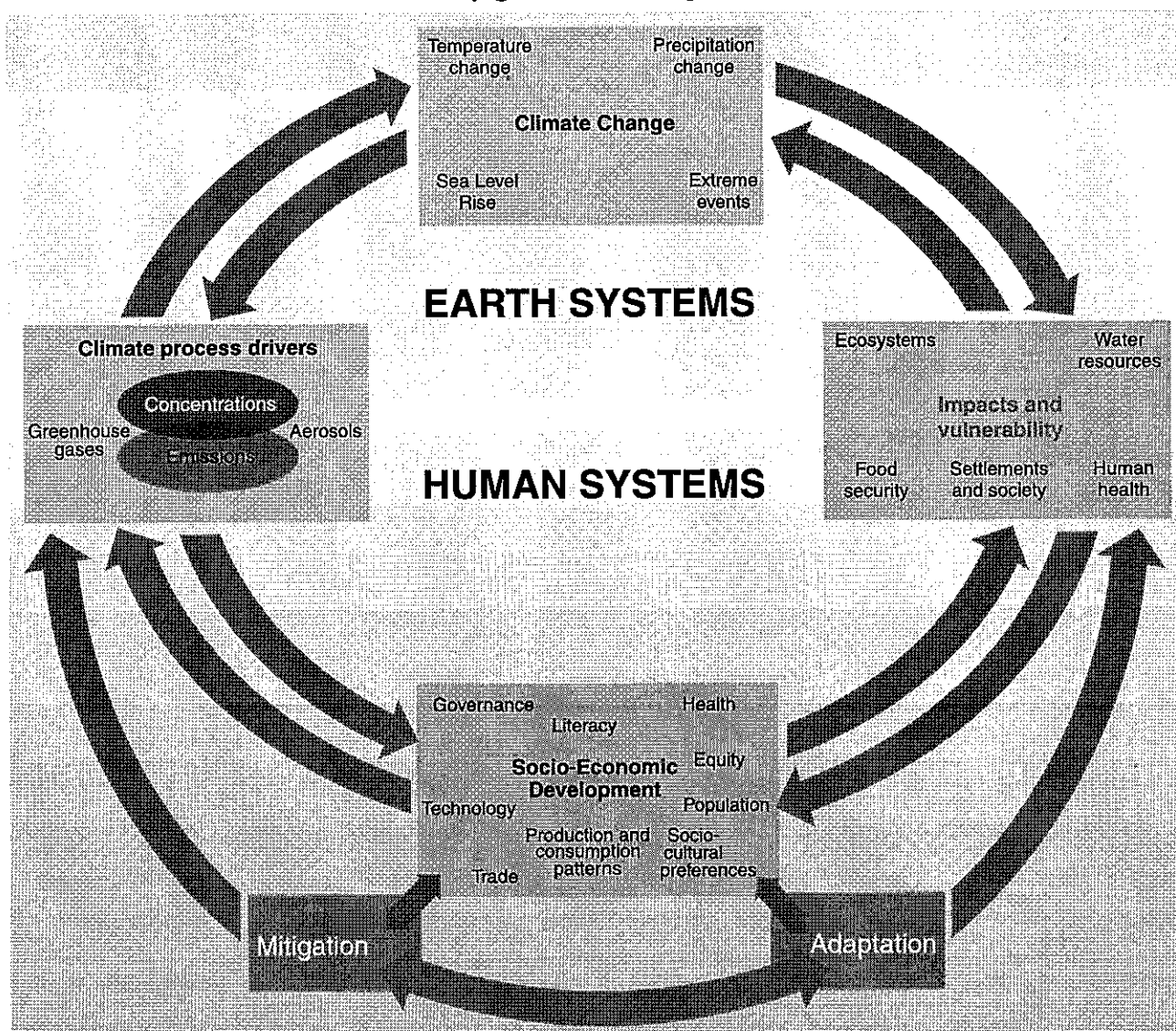


Figure I.1. Schematic framework representing anthropogenic drivers, impacts of and responses to climate change, and their linkages.

Treatment of uncertainty

The IPCC uncertainty guidance note¹ defines a framework for the treatment of uncertainties across all WGs and in this Synthesis Report. This framework is broad because the WGs assess material from different disciplines and cover a diversity of approaches to the treatment of uncertainty drawn from the literature. The nature of data, indicators and analyses used in the natural sciences is generally different from that used in assessing technology development or the social sciences. WG I focuses on the former, WG III on the latter, and WG II covers aspects of both.

Three different approaches are used to describe uncertainties each with a distinct form of language. Choices among and within these three approaches depend on both the nature of the information available and the authors' expert judgment of the correctness and completeness of current scientific understanding.

Where uncertainty is assessed qualitatively, it is characterised by providing a relative sense of the amount and quality of evidence (that is, information from theory, observations or models indicating whether a belief or proposition is true or valid) and the degree of agreement (that is, the level of concurrence in the literature on a particular finding). This approach is used by WG III through a series of self-explanatory terms such as: *high agreement, much evidence; high agreement, medium evidence; medium agreement, medium evidence; etc.*

Where uncertainty is assessed more quantitatively using expert judgement of the correctness of underlying data, models or analyses, then the following scale of confidence levels is used to express the assessed chance of a finding being correct: *very high confidence* at least 9 out of 10; *high confidence* about 8 out of 10; *medium confidence* about 5 out of 10; *low confidence* about 2 out of 10; and *very low confidence* less than 1 out of 10.

Where uncertainty in specific outcomes is assessed using expert judgment and statistical analysis of a body of evidence (e.g. observations or model results), then the following likelihood ranges are used to express the assessed probability of occurrence: *virtually certain* >99%; *extremely likely* >95%; *very likely* >90%; *likely* >66%; *more likely than not* > 50%; *about as likely as not* 33% to 66%; *unlikely* <33%; *very unlikely* <10%; *extremely unlikely* <5%; *exceptionally unlikely* <1%.

WG II has used a combination of confidence and likelihood assessments and WG I has predominantly used likelihood assessments.

This Synthesis Report follows the uncertainty assessment of the underlying WGs. Where synthesised findings are based on information from more than one WG, the description of uncertainty used is consistent with that for the components drawn from the respective WG reports.

Unless otherwise stated, numerical ranges given in square brackets in this report indicate 90% uncertainty intervals (i.e. there is an estimated 5% likelihood that the value could be above the range given in square brackets and 5% likelihood that the value could be below that range). Uncertainty intervals are not necessarily symmetric around the best estimate.

¹ See <http://www.ipcc.ch/meetings/ar4-workshops-express-meetings/uncertainty-guidance-note.pdf>

1

Observed changes in climate and their effects

1.1 Observations of climate change

Since the TAR, progress in understanding how climate is changing in space and time has been gained through improvements and extensions of numerous datasets and data analyses, broader geographical coverage, better understanding of uncertainties and a wider variety of measurements. *{WGI SPM}*

Definitions of climate change

Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (Figure 1.1). *{WGI 3.2, 4.8, 5.2, 5.5, SPM}*

Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906-2005) of 0.74 [0.56 to 0.92]°C is larger than the corresponding trend of 0.6 [0.4 to 0.8]°C (1901-2000) given in the TAR (Figure 1.1). The linear warming trend over the 50 years from 1956 to 2005 (0.13 [0.10 to 0.16]°C per decade) is nearly twice that for the 100 years from 1906 to 2005. *{WGI 3.2, SPM}*

The temperature increase is widespread over the globe and is greater at higher northern latitudes (Figure 1.2). Average Arctic temperatures have increased at almost twice the global average rate in the past 100 years. Land regions have warmed faster than the oceans (Figures 1.2 and 2.5). Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000m and that the ocean has been taking up over 80% of the heat being added to the climate system. New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates similar to those observed in surface temperature. *{WGI 3.2, 3.4, 5.2, SPM}*

Increases in sea level are consistent with warming (Figure 1.1). Global average sea level rose at an average rate of 1.8 [1.3 to 2.3]mm per year over 1961 to 2003 and at an average rate of about 3.1 [2.4 to 3.8]mm per year from 1993 to 2003. Whether this faster rate for 1993 to 2003 reflects decadal variation or an increase in the longer-

term trend is unclear. Since 1993 thermal expansion of the oceans has contributed about 57% of the sum of the estimated individual contributions to the sea level rise, with decreases in glaciers and ice caps contributing about 28% and losses from the polar ice sheets contributing the remainder. From 1993 to 2003 the sum of these climate contributions is consistent within uncertainties with the total sea level rise that is directly observed. *{WGI 4.6, 4.8, 5.5, SPM, Table SPM.1}*

Observed decreases in snow and ice extent are also consistent with warming (Figure 1.1). Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 [2.1 to 3.3]% per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade. Mountain glaciers and snow cover on average have declined in both hemispheres. The maximum areal extent of seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900, with decreases in spring of up to 15%. Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic by up to 3°C. *{WGI 3.2, 4.5, 4.6, 4.7, 4.8, 5.5, SPM}*

At continental, regional and ocean basin scales, numerous long-term changes in other aspects of climate have also been observed. Trends from 1900 to 2005 have been observed in precipitation amount in many large regions. Over this period, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia whereas precipitation declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Globally, the area affected by drought has *likely*² increased since the 1970s. *{WGI 3.3, 3.9, SPM}*

Some extreme weather events have changed in frequency and/or intensity over the last 50 years:

- It is *very likely* that cold days, cold nights and frosts have become less frequent over most land areas, while hot days and hot nights have become more frequent. *{WGI 3.8, SPM}*
- It is *likely* that heat waves have become more frequent over most land areas. *{WGI 3.8, SPM}*
- It is *likely* that the frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over most areas. *{WGI 3.8, 3.9, SPM}*
- It is *likely* that the incidence of extreme high sea level³ has increased at a broad range of sites worldwide since 1975. *{WGI 5.5, SPM}*

There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, and suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. *{WGI 3.8, SPM}*

Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years. *{WGI 6.6, SPM}*

² Likelihood and confidence statements in italics represent calibrated expressions of uncertainty and confidence. See Box 'Treatment of uncertainty' in the Introduction for an explanation of these terms.

³ Excluding tsunamis, which are not due to climate change. Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.

Changes in temperature, sea level and Northern Hemisphere snow cover

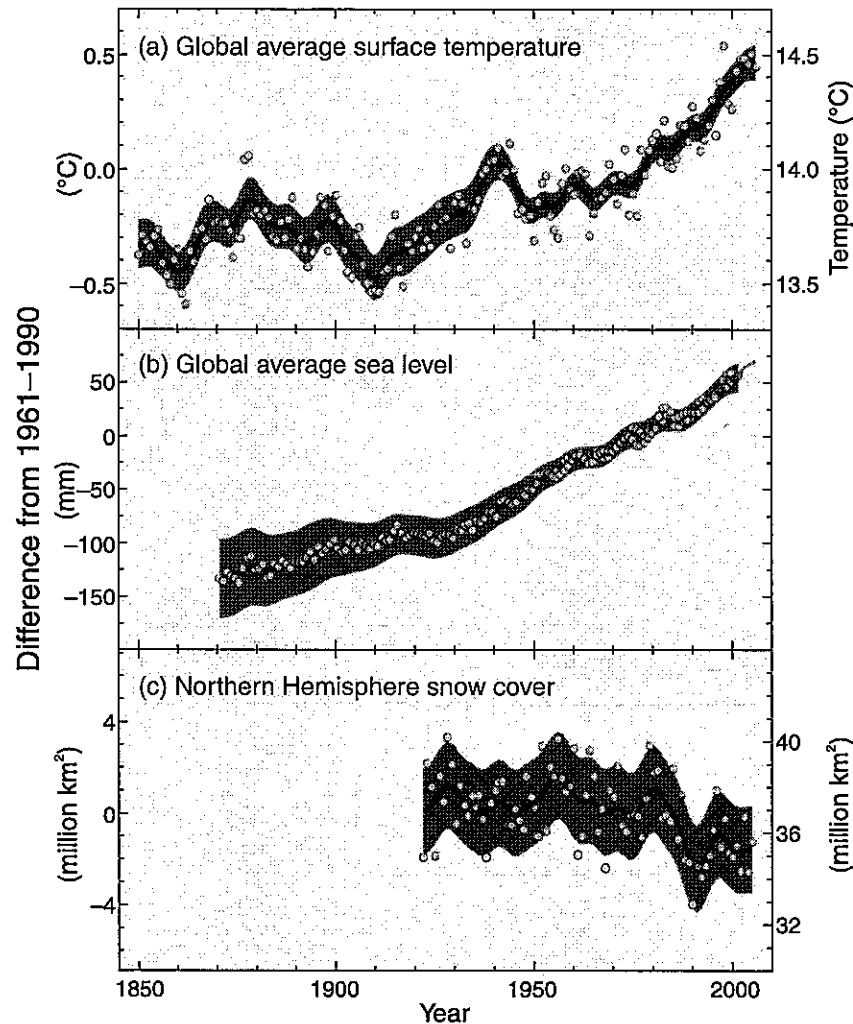


Figure 1.1. Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data; and (c) Northern Hemisphere snow cover for March–April. All differences are relative to corresponding averages for the period 1961–1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). {WGII FAQ 3.1 Figure 1, Figure 4.2, Figure 5.13, Figure SPM.3}

1.2 Observed effects of climate changes

The statements presented here are based largely on data sets that cover the period since 1970. The number of studies of observed trends in the physical and biological environment and their relationship to regional climate changes has increased greatly since the TAR. The quality of the data sets has also improved. There is a notable lack of geographic balance in data and literature on observed changes, with marked scarcity in developing countries. {WGII SPM}

These studies have allowed a broader and more confident assessment of the relationship between observed warming and impacts than was made in the TAR. That assessment concluded that “there is *high confidence*² that recent regional changes in temperature have had discernible impacts on physical and biological systems”. {WGII SPM}

Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. {WGII SPM}

There is *high confidence* that natural systems related to snow, ice and frozen ground (including permafrost) are affected. Examples are:

- enlargement and increased numbers of glacial lakes {WGII 1.3, SPM}
- increasing ground instability in permafrost regions and rock avalanches in mountain regions {WGII 1.3, SPM}
- changes in some Arctic and Antarctic ecosystems, including those in sea-ice biomes, and predators at high levels of the food web. {WGII 1.3, 4.4, 15.4, SPM}

Based on growing evidence, there is *high confidence* that the following effects on hydrological systems are occurring: increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers, and warming of lakes and rivers in many regions, with effects on thermal structure and water quality. {WGII 1.3, 15.2, SPM}

Changes in physical and biological systems and surface temperature 1970-2004

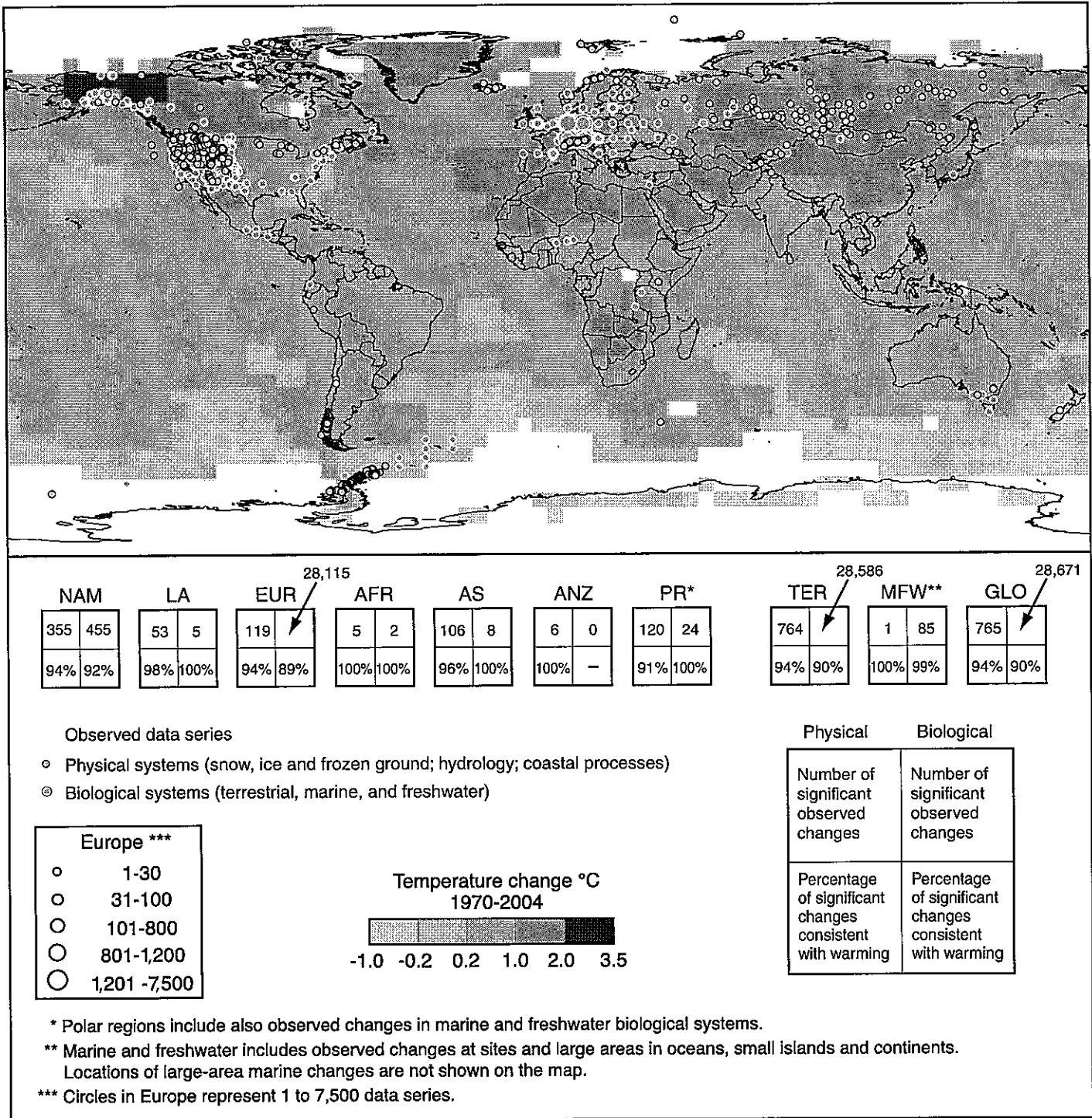


Figure 1.2. Locations of significant changes in data series of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine, and freshwater biological systems), are shown together with surface air temperature changes over the period 1970-2004. A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (1) ending in 1990 or later; (2) spanning a period of at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies. These data series are from about 75 studies (of which about 70 are new since the TAR) and contain about 29,000 data series, of which about 28,000 are from European studies. White areas do not contain sufficient observational climate data to estimate a temperature trend. The 2 x 2 boxes show the total number of data series with significant changes (top row) and the percentage of those consistent with warming (bottom row) for (i) continental regions: North America (NAM), Latin America (LA), Europe (EUR), Africa (AFR), Asia (AS), Australia and New Zealand (ANZ), and Polar Regions (PR) and (ii) global-scale: Terrestrial (TER), Marine and Freshwater (MFW), and Global (GLO). The numbers of studies from the seven regional boxes (NAM, ..., PR) do not add up to the global (GLO) totals because numbers from regions except Polar do not include the numbers related to Marine and Freshwater (MFW) systems. Locations of large-area marine changes are not shown on the map. [WGII Figure SPM.1, Figure 1.8, Figure 1.9; WGI Figure 3.9b]

There is *very high confidence*, based on more evidence from a wider range of species, that recent warming is strongly affecting terrestrial biological systems, including such changes as earlier timing of spring events, such as leaf-unfolding, bird migration and egg-laying; and poleward and upward shifts in ranges in plant and animal species. Based on satellite observations since the early 1980s, there is *high confidence* that there has been a trend in many regions towards earlier ‘greening’ of vegetation in the spring linked to longer thermal growing seasons due to recent warming. *{WGII 1.3, 8.2, 14.2, SPM}*

There is *high confidence*, based on substantial new evidence, that observed changes in marine and freshwater biological systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation. These include: shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans; increases in algal and zooplankton abundance in high-latitude and high-altitude lakes; and range changes and earlier fish migrations in rivers. While there is increasing evidence of climate change impacts on coral reefs, separating the impacts of climate-related stresses from other stresses (e.g. over-fishing and pollution) is difficult. *{WGII 1.3, SPM}*

Other effects of regional climate changes on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers. *{WGII SPM}*

Effects of temperature increases have been documented with *medium confidence* in the following managed and human systems:

- agricultural and forestry management at Northern Hemisphere higher latitudes, such as earlier spring planting of crops, and alterations in disturbances of forests due to fires and pests *{WGII 1.3, SPM}*
- some aspects of human health, such as excess heat-related mortality in Europe, changes in infectious disease vectors in parts of Europe, and earlier onset of and increases in seasonal production of allergenic pollen in Northern Hemisphere high and mid-latitudes *{WGII 1.3, 8.2, 8.ES, SPM}*
- some human activities in the Arctic (e.g. hunting and shorter

travel seasons over snow and ice) and in lower-elevation alpine areas (such as limitations in mountain sports). *{WGII 1.3, SPM}*

Sea level rise and human development are together contributing to losses of coastal wetlands and mangroves and increasing damage from coastal flooding in many areas. However, based on the published literature, the impacts have not yet become established trends. *{WGII 1.3, 1.ES, SPM}*

1.3 Consistency of changes in physical and biological systems with warming

Changes in the ocean and on land, including observed decreases in snow cover and Northern Hemisphere sea ice extent, thinner sea ice, shorter freezing seasons of lake and river ice, glacier melt, decreases in permafrost extent, increases in soil temperatures and borehole temperature profiles, and sea level rise, provide additional evidence that the world is warming. *{WGI 3.9}*

Of the more than 29,000 observational data series, from 75 studies, that show significant change in many physical and biological systems, more than 89% are consistent with the direction of change expected as a response to warming (Figure 1.2). *{WGII 1.4, SPM}*

1.4 Some aspects of climate have not been observed to change

Some aspects of climate appear not to have changed and, for some, data inadequacies mean that it cannot be determined if they have changed. Antarctic sea ice extent shows inter-annual variability and localised changes but no statistically significant average multi-decadal trend, consistent with the lack of rise in near-surface atmospheric temperatures averaged across the continent. There is insufficient evidence to determine whether trends exist in some other variables, for example the meridional overturning circulation (MOC) of the global ocean or small-scale phenomena such as tornadoes, hail, lightning and dust storms. There is no clear trend in the annual numbers of tropical cyclones. *{WGI 3.2, 3.8, 4.4, 5.3, SPM}*

2

Causes of change

Causes of change

This Topic considers both natural and anthropogenic drivers of climate change, including the chain from greenhouse gas (GHG) emissions to atmospheric concentrations to radiative forcing⁴ to climate responses and effects.

2.1 Emissions of long-lived GHGs

The radiative forcing of the climate system is dominated by the long-lived GHGs, and this section considers those whose emissions are covered by the UNFCCC.

Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 (Figure 2.1).⁵ {WGIII 1.3, SPM}

Carbon dioxide (CO₂) is the most important anthropogenic GHG. Its annual emissions have grown between 1970 and 2004 by about 80%, from 21 to 38 gigatonnes (Gt), and represented 77% of total anthropogenic GHG emissions in 2004 (Figure 2.1). The rate of growth of CO₂-eq emissions was much higher during the recent 10-year period of 1995-2004 (0.92 GtCO₂-eq per year) than during the previous period of 1970-1994 (0.43 GtCO₂-eq per year). {WGIII 1.3, TS.1, SPM}

Carbon dioxide-equivalent (CO₂-eq) emissions and concentrations

GHGs differ in their warming influence (radiative forcing) on the global climate system due to their different radiative properties and lifetimes in the atmosphere. These warming influences may be expressed through a common metric based on the radiative forcing of CO₂.

- **CO₂-equivalent emission** is the amount of CO₂ emission that would cause the same time-integrated radiative forcing, over a given time horizon, as an emitted amount of a long-lived GHG or a mixture of GHGs. The equivalent CO₂ emission is obtained by multiplying the emission of a GHG by its Global Warming Potential (GWP) for the given time horizon.⁶ For a mix of GHGs it is obtained by summing the equivalent CO₂ emissions of each gas. Equivalent CO₂ emission is a standard and useful metric for comparing emissions of different GHGs but does not imply the same climate change responses (see WGI 2.10).
- **CO₂-equivalent concentration** is the concentration of CO₂ that would cause the same amount of radiative forcing as a given mixture of CO₂ and other forcing components.⁷

The largest growth in GHG emissions between 1970 and 2004 has come from energy supply, transport and industry, while residential and commercial buildings, forestry (including deforestation) and agriculture sectors have been growing at a lower rate. The

Global anthropogenic GHG emissions

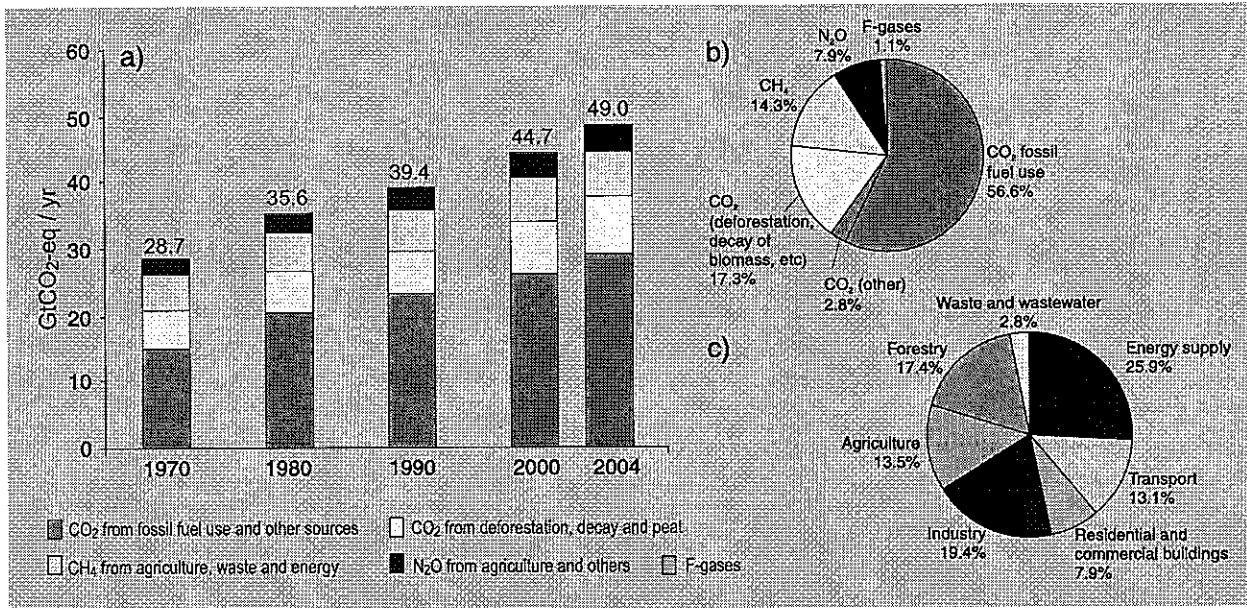


Figure 2.1. (a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.⁵ (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO₂-eq. (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO₂-eq. (Forestry includes deforestation.) {WGIII Figures TS.1a, TS.1b, TS.2b}

⁴ *Radiative forcing* is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. In this report radiative forcing values are for changes relative to pre-industrial conditions defined at 1750 and are expressed in watts per square metre (W/m²).

⁵ Includes only carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphurhexafluoride (SF₆), whose emissions are covered by the UNFCCC. These GHGs are weighted by their 100-year Global Warming Potentials (GWPs), using values consistent with reporting under the UNFCCC.

⁶ This report uses 100-year GWPs and numerical values consistent with reporting under the UNFCCC.

⁷ Such values may consider only GHGs, or a combination of GHGs and aerosols.

sectoral sources of GHGs in 2004 are considered in Figure 2.1c. *{WGIII 1.3, SPM}*

The effect on global emissions of the decrease in global energy intensity (-33%) during 1970 to 2004 has been smaller than the combined effect of global income growth (77%) and global population growth (69%); both drivers of increasing energy-related CO₂ emissions. The long-term trend of declining CO₂ emissions per unit of energy supplied reversed after 2000. *{WGIII 1.3, Figure SPM.2, SPM}*

Differences in per capita income, per capita emissions and energy intensity among countries remain significant. In 2004, UNFCCC Annex I countries held a 20% share in world population, produced 57% of the world's Gross Domestic Product based on Purchasing Power Parity (GDP_{PPP}) and accounted for 46% of global GHG emissions (Figure 2.2). *{WGIII 1.3, SPM}*

2.2 Drivers of climate change

Changes in the atmospheric concentrations of GHGs and aerosols, land cover and solar radiation alter the energy balance of the climate system and are drivers of climate change. They affect the absorption, scattering and emission of radiation within the atmosphere and at the Earth's surface. The resulting positive or negative changes in energy balance due to these factors are expressed as radiative forcing⁴, which is used to compare warming or cooling influences on global climate. *{WGI TS.2}*

Human activities result in emissions of four long-lived GHGs: CO₂, methane (CH₄), nitrous oxide (N₂O) and halocarbons (a group of gases containing fluorine, chlorine or bromine). Atmospheric concentrations of GHGs increase when emissions are larger than removal processes.

Global atmospheric concentrations of CO₂, CH₄ and N₂O have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years

(Figure 2.3). The atmospheric concentrations of CO₂ and CH₄ in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO₂ concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is *very likely* that the observed increase in CH₄ concentration is predominantly due to agriculture and fossil fuel use. The increase in N₂O concentration is primarily due to agriculture. *{WGI 2.3, 7.3, SPM}*

The global atmospheric concentration of CO₂ increased from a pre-industrial value of about 280ppm to 379ppm in 2005. The annual CO₂ concentration growth rate was larger during the last 10 years (1995-2005 average: 1.9ppm per year) than it has been since the beginning of continuous direct atmospheric measurements (1960-2005 average: 1.4ppm per year), although there is year-to-year variability in growth rates. *{WGI 2.3, 7.3, SPM; WGIII 1.3}*

The global atmospheric concentration of CH₄ has increased from a pre-industrial value of about 715ppb to 1732ppb in the early 1990s, and was 1774ppb in 2005. Growth rates have declined since the early 1990s, consistent with total emissions (sum of anthropogenic and natural sources) being nearly constant during this period. *{WGI 2.3, 7.4, SPM}*

The global atmospheric N₂O concentration increased from a pre-industrial value of about 270ppb to 319ppb in 2005. *{WGI 2.3, 7.4, SPM}*

Many halocarbons (including hydrofluorocarbons) have increased from a near-zero pre-industrial background concentration, primarily due to human activities. *{WGI 2.3, SPM; SROC SPM}*

There is very high confidence that the global average net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W/m² (Figure 2.4). *{WGI 2.3, 6.5, 2.9, SPM}*

The combined radiative forcing due to increases in CO₂, CH₄ and N₂O is +2.3 [+2.1 to +2.5] W/m², and its rate of increase during

Regional distribution of GHG emissions by population and by GDP_{PPP}

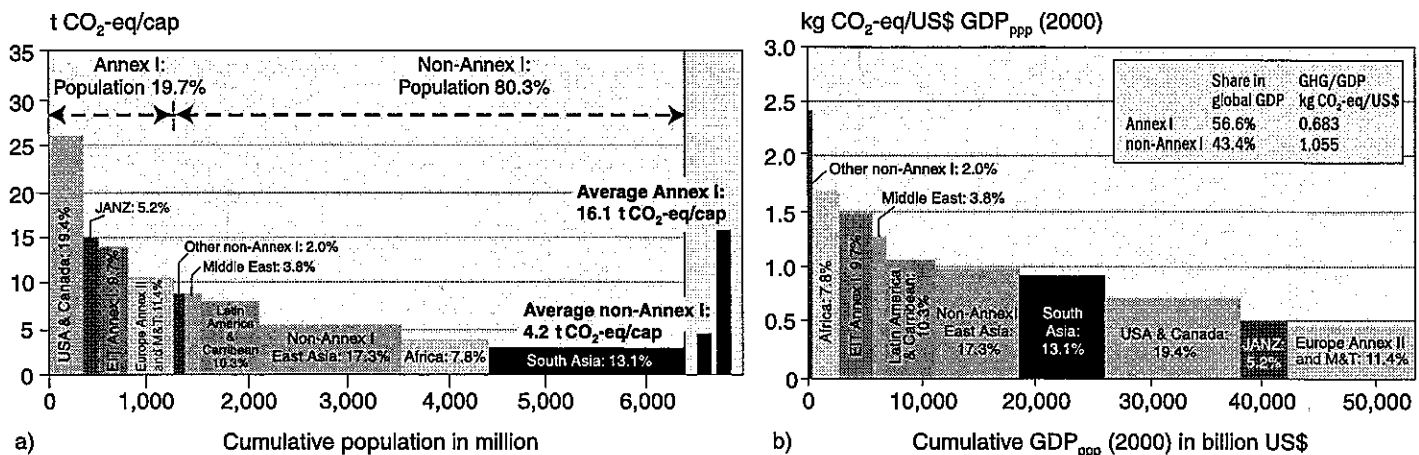


Figure 2.2. (a) Distribution of regional per capita GHG emissions according to the population of different country groupings in 2004 (see appendix for definitions of country groupings). (b) Distribution of regional GHG emissions per US\$ of GDP_{PPP} over the GDP of different country groupings in 2004. The percentages in the bars in both panels indicate a region's share in global GHG emissions. *{WGIII Figures SPM.3a, SPM.3b}*

Changes in GHGs from ice core and modern data

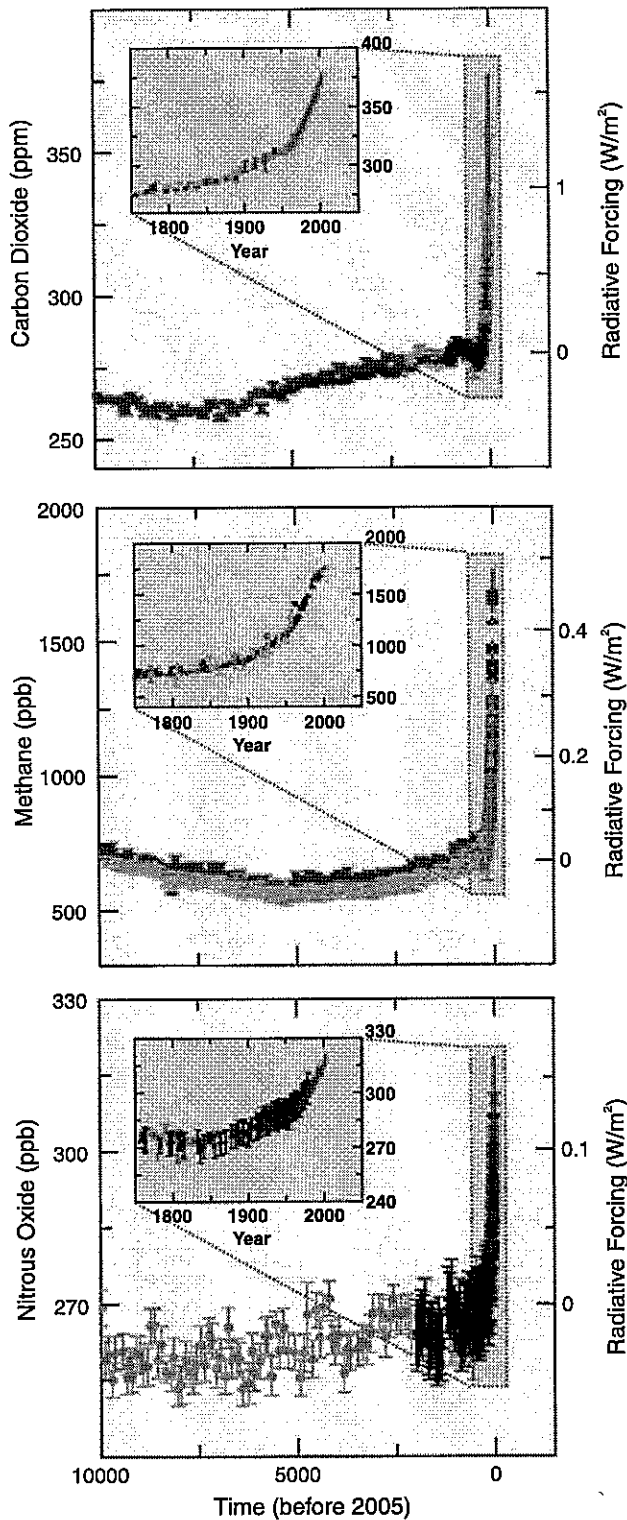


Figure 2.3. Atmospheric concentrations of CO₂, CH₄ and N₂O over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings relative to 1750 are shown on the right hand axes of the large panels. {WGI Figure SPM.1}

the industrial era is *very likely* to have been unprecedented in more than 10,000 years (Figures 2.3 and 2.4). The CO₂ radiative forcing increased by 20% from 1995 to 2005, the largest change for any decade in at least the last 200 years. {WGI 2.3, 6.4, SPM}

Anthropogenic contributions to aerosols (primarily sulphate, organic carbon, black carbon, nitrate and dust) together produce a cooling effect, with a total direct radiative forcing of -0.5 [-0.9 to -0.1] W/m² and an indirect cloud albedo forcing of -0.7 [-1.8 to -0.3] W/m². Aerosols also influence precipitation. {WGI 2.4, 2.9, 7.5, SPM}

In comparison, changes in solar irradiance since 1750 are estimated to have caused a small radiative forcing of +0.12 [+0.06 to +0.30] W/m², which is less than half the estimate given in the TAR. {WGI 2.7, SPM}

2.3 Climate sensitivity and feedbacks

The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing. It is defined as the equilibrium global average surface warming following a doubling of CO₂ concentration. Progress since the TAR enables an assessment that climate sensitivity is *likely* to be in the range of 2 to 4.5°C with a best estimate of about 3°C, and is *very unlikely* to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded, but agreement of models with observations is not as good for those values. {WGI 8.6, 9.6, Box 10.2, SPM}

Feedbacks can amplify or dampen the response to a given forcing. Direct emission of water vapour (a greenhouse gas) by human activities makes a negligible contribution to radiative forcing. However, as global average temperature increases, tropospheric water vapour concentrations increase and this represents a key positive feedback but not a forcing of climate change. Water vapour changes represent the largest feedback affecting equilibrium climate sensitivity and are now better understood than in the TAR. Cloud feedbacks remain the largest source of uncertainty. Spatial patterns of climate response are largely controlled by climate processes and feedbacks. For example, sea-ice albedo feedbacks tend to enhance the high latitude response. {WGI 2.8, 8.6, 9.2, TS.2.1.3, TS.2.5, SPM}

Warming reduces terrestrial and ocean uptake of atmospheric CO₂, increasing the fraction of anthropogenic emissions remaining in the atmosphere. This positive carbon cycle feedback leads to larger atmospheric CO₂ increases and greater climate change for a given emissions scenario, but the strength of this feedback effect varies markedly among models. {WGI 7.3, TS.5.4, SPM; WGII 4.4}

2.4 Attribution of climate change

Attribution evaluates whether observed changes are quantitatively consistent with the expected response to external forcings (e.g. changes in solar irradiance or anthropogenic GHGs) and inconsistent with alternative physically plausible explanations. {WGI TS.4, SPM}

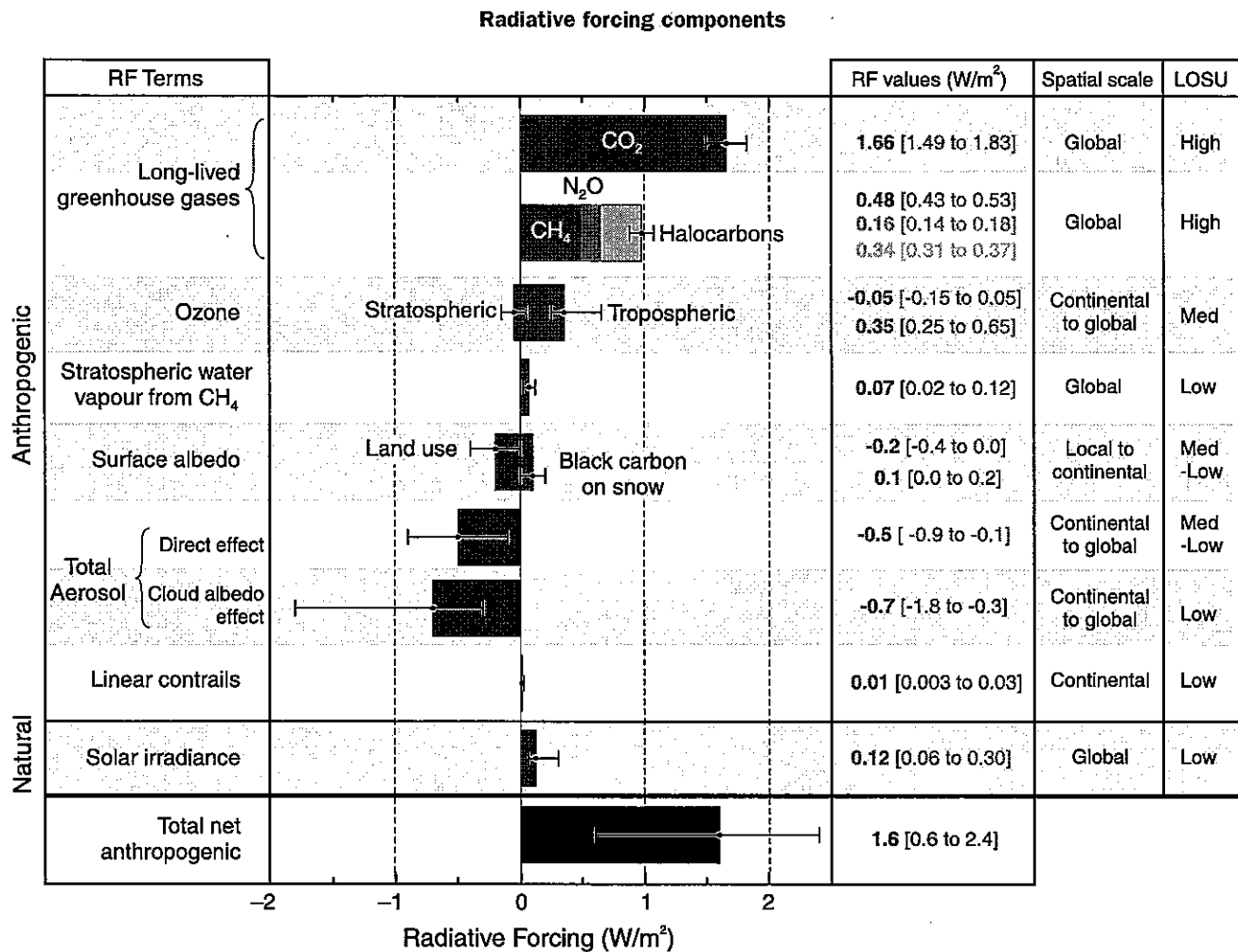


Figure 2.4. Global average radiative forcing (RF) in 2005 (best estimates and 5 to 95% uncertainty ranges) with respect to 1750 for CO₂, CH₄, N₂O and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). Aerosols from explosive volcanic eruptions contribute an additional episodic cooling term for a few years following an eruption. The range for linear contrails does not include other possible effects of aviation on cloudiness. {WGI Figure SPM.2}

Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations.⁸ This is an advance since the TAR’s conclusion that “most of the observed warming over the last 50 years is *likely* to have been due to the increase in GHG concentrations” (Figure 2.5). {WGI 9.4, SPM}

The observed widespread warming of the atmosphere and ocean, together with ice mass loss, support the conclusion that it is *extremely unlikely* that global climate change of the past 50 years can be explained without external forcing and *very likely* that it is not due to known natural causes alone. During this period, the sum of solar and volcanic forcings would *likely* have produced cooling, not warming. Warming of the climate system has been detected in changes in surface and atmospheric temperatures and in temperatures of the upper several hundred metres of the ocean. The observed pattern of tropospheric warming and stratospheric cooling

is *very likely* due to the combined influences of GHG increases and stratospheric ozone depletion. It is *likely* that increases in GHG concentrations alone would have caused more warming than observed because volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place. {WGI 2.9, 3.2, 3.4, 4.8, 5.2, 7.5, 9.4, 9.5, 9.7, TS.4.1, SPM}

It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica) (Figure 2.5). {WGI 3.2, 9.4, SPM}

The observed patterns of warming, including greater warming over land than over the ocean, and their changes over time, are simulated only by models that include anthropogenic forcing. No coupled global climate model that has used natural forcing only has reproduced the continental mean warming trends in individual continents (except Antarctica) over the second half of the 20th century. {WGI 3.2, 9.4, TS.4.2, SPM}

⁸ Consideration of remaining uncertainty is based on current methodologies.

Global and continental temperature change

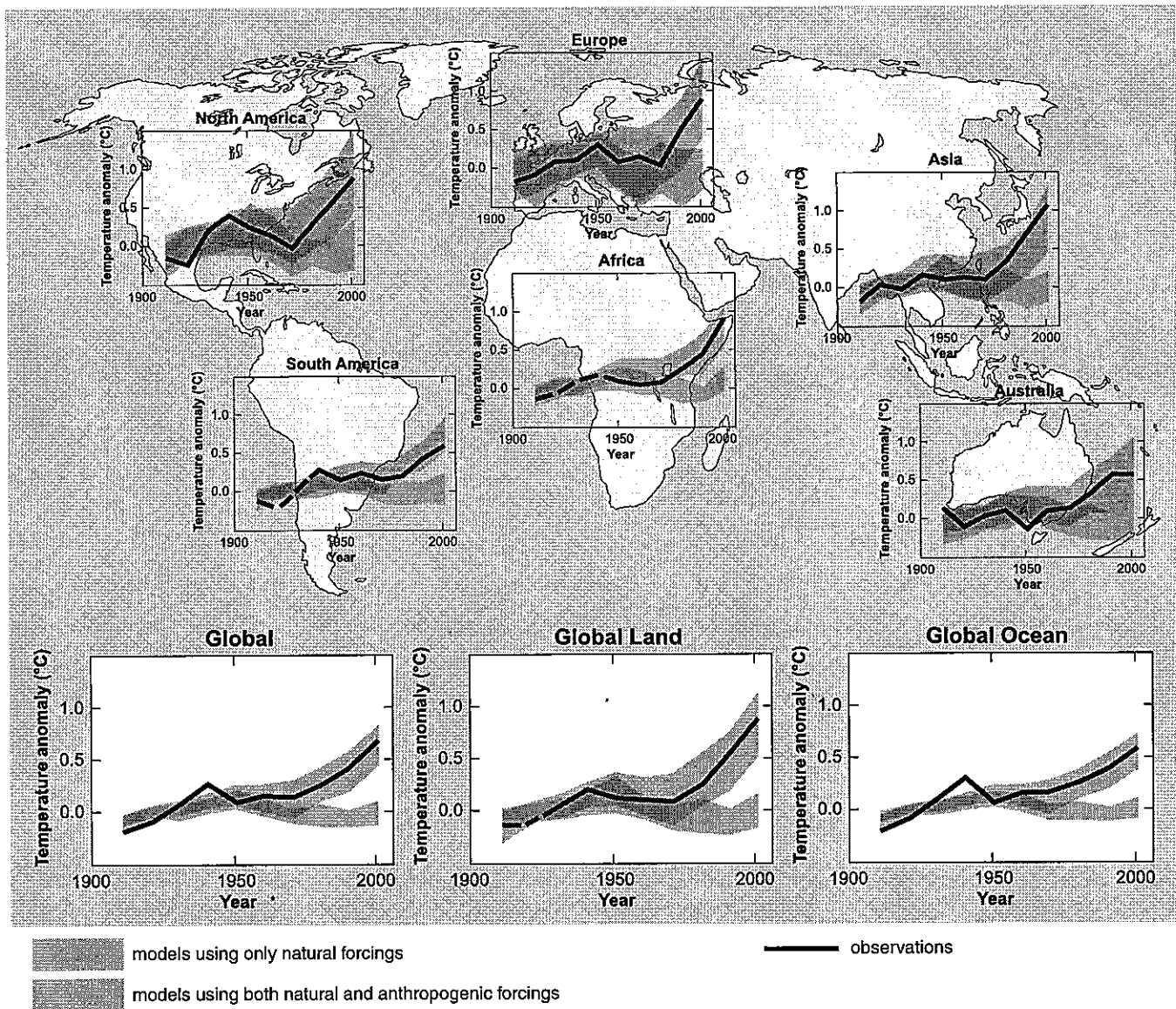


Figure 2.5. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the 1901-1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5 to 95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. (WGI Figure SPM.4)

Difficulties remain in simulating and attributing observed temperature changes at smaller scales. On these scales, natural climate variability is relatively larger, making it harder to distinguish changes expected due to external forcings. Uncertainties in local forcings, such as those due to aerosols and land-use change, and feedbacks also make it difficult to estimate the contribution of GHG increases to observed small-scale temperature changes. (WGI 8.3, 9.4, SPM)

Advances since the TAR show that discernible human influences extend beyond average temperature to other aspects of climate, including temperature extremes and wind patterns. (WGI 9.4, 9.5, SPM)

Temperatures of the most extreme hot nights, cold nights and cold days are likely to have increased due to anthropogenic forcing. It is more likely than not that anthropogenic forcing has increased the risk of heat waves. Anthropogenic forcing is likely to have contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns in both hemispheres. However, the observed changes in the Northern Hemisphere circulation are larger than simulated by models in response to 20th century forcing change. (WGI 3.5, 3.6, 9.4, 9.5, 10.3, SPM)

It is very likely that the response to anthropogenic forcing contributed to sea level rise during the latter half of the 20th century. There is some evidence of the impact of human climatic influence

on the hydrological cycle, including the observed large-scale patterns of changes in land precipitation over the 20th century. It is *more likely than not* that human influence has contributed to a global trend towards increases in area affected by drought since the 1970s and the frequency of heavy precipitation events. {WGI 3.3, 5.5, 9.5, TS.4.1, TS.4.3}

Anthropogenic warming over the last three decades has likely had a discernible influence at the global scale on observed changes in many physical and biological systems. {WGII 1.4}

A synthesis of studies strongly demonstrates that the spatial agreement between regions of significant warming across the globe and the locations of significant observed changes in many natural systems consistent with warming is *very unlikely* to be due solely to natural variability of temperatures or natural variability of the

systems. Several modelling studies have linked some specific responses in physical and biological systems to anthropogenic warming, but only a few such studies have been performed. Taken together with evidence of significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica), it is *likely* that anthropogenic warming over the last three decades has had a discernible influence on many natural systems. {WGI 3.2, 9.4, SPM; WGII 1.4, SPM}

Limitations and gaps currently prevent more complete attribution of the causes of observed natural system responses to anthropogenic warming. The available analyses are limited in the number of systems, length of records and locations considered. Natural temperature variability is larger at the regional than the global scale, thus affecting identification of changes to external forcing. At the regional scale, other non-climate factors (such as land-use change, pollution and invasive species) are influential. {WGII 1.2, 1.3, 1.4, SPM}

3

Climate change and its impacts in the near and long term under different scenarios

3.1 Emissions scenarios

There is *high agreement* and *much evidence*⁹ that with current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. Baseline emissions scenarios published since the IPCC Special Report on Emissions Scenarios (SRES, 2000) are comparable in range to those presented in SRES (see Box on SRES scenarios and Figure 3.1).¹⁰ {WGIII 1.3, 3.2, SPM}

The SRES scenarios project an increase of baseline global GHG emissions by a range of 9.7 to 36.7 GtCO₂-eq (25 to 90%) between 2000 and 2030. In these scenarios, fossil fuels are projected to maintain their dominant position in the global energy mix to 2030 and beyond. Hence CO₂ emissions from energy use between 2000 and 2030 are projected to grow 40 to 110% over that period. {WGIII 1.3, SPM}

Studies published since SRES (i.e. post-SRES scenarios) have used lower values for some drivers for emissions, notably population projections. However, for those studies incorporating these new population projections, changes in other drivers, such as economic growth, result in little change in overall emission levels. Economic growth projections for Africa, Latin America and the Middle East to 2030 in post-SRES baseline scenarios are lower than in SRES, but this has only minor effects on global economic growth and overall emissions. {WGIII 3.2, TS.3, SPM}

Aerosols have a net cooling effect and the representation of aerosol and aerosol precursor emissions, including sulphur dioxide, black carbon and organic carbon, has improved in the post-SRES scenarios. Generally, these emissions are projected to be lower than reported in SRES. {WGIII 3.2, TS.3, SPM}

Available studies indicate that the choice of exchange rate for Gross Domestic Product (GDP) (Market Exchange Rate, MER or

Scenarios for GHG emissions from 2000 to 2100 in the absence of additional climate policies

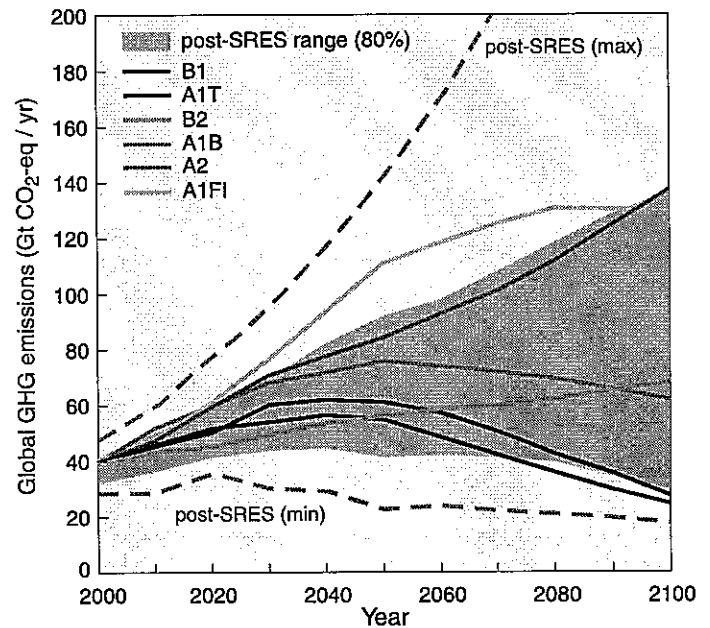


Figure 3.1. Global GHG emissions (in GtCO₂-eq per year) in the absence of additional climate policies: six illustrative SRES marker scenarios (coloured lines) and 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include CO₂, CH₄, N₂O and F-gases. {WGIII 1.3, 3.2, Figure SPM.4}

Purchasing Power Parity, PPP) does not appreciably affect the projected emissions, when used consistently.¹¹ The differences, if any, are small compared to the uncertainties caused by assumptions on other parameters in the scenarios, e.g. technological change. {WGIII 3.2, TS.3, SPM}

SRES scenarios

SRES refers to the scenarios described in the IPCC Special Report on Emissions Scenarios (SRES, 2000). The SRES scenarios are grouped into four scenario families (A1, A2, B1 and B2) that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting GHG emissions. The SRES scenarios do not include additional climate policies above current ones. The emissions projections are widely used in the assessments of future climate change, and their underlying assumptions with respect to socio-economic, demographic and technological change serve as inputs to many recent climate change vulnerability and impact assessments. {WGI 10.1; WGII 2.4; WGIII TS.1, SPM}

The A1 storyline assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B). B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy. B2 describes a world with intermediate population and economic growth, emphasising local solutions to economic, social, and environmental sustainability. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change. No likelihood has been attached to any of the SRES scenarios. {WGIII TS.1, SPM}

⁹ Agreement/evidence statements in italics represent calibrated expressions of uncertainty and confidence. See Box 'Treatment of uncertainty' in the Introduction for an explanation of these terms.

¹⁰ Baseline scenarios do not include additional climate policies above current ones; more recent studies differ with respect to UNFCCC and Kyoto Protocol inclusion. Emission pathways of mitigation scenarios are discussed in Topic 5.

¹¹ Since the TAR, there has been a debate on the use of different exchange rates in emissions scenarios. Two metrics are used to compare GDP between countries. Use of MER is preferable for analyses involving internationally traded products. Use of PPP is preferable for analyses involving comparisons of income between countries at very different stages of development. Most of the monetary units in this report are expressed in MER. This reflects the large majority of emissions mitigation literature that is calibrated in MER. When monetary units are expressed in PPP, this is denoted by GDP_{PPP}. {WGIII SPM}

3.2 Projections of future changes in climate

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emissions scenarios. Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. Afterwards, temperature projections increasingly depend on specific emissions scenarios (Figure 3.2). {WGI 10.3, 10.7; WGIII 3.2}

Since the IPCC's first report in 1990, assessed projections have suggested global averaged temperature increases between about 0.15 and 0.3°C per decade from 1990 to 2005. This can now be compared with observed values of about 0.2°C per decade, strengthening confidence in near-term projections. {WGI 1.2, 3.2}

3.2.1 21st century global changes

Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century. {WGI 10.3}

Advances in climate change modelling now enable best estimates and *likely* assessed uncertainty ranges to be given for projected warming for different emissions scenarios. Table 3.1 shows best estimates and *likely* ranges for global average surface air warming for the six SRES marker emissions scenarios (including climate-carbon cycle feedbacks). {WGI 10.5}

Although these projections are broadly consistent with the span quoted in the TAR (1.4 to 5.8°C), they are not directly comparable. Assessed upper ranges for temperature projections are larger than in the TAR mainly because the broader range of models now available suggests stronger climate-carbon cycle feedbacks. For the A2 scenario, for example, the climate-carbon cycle feedback increases the corresponding global average warming at 2100 by more than 1°C. Carbon feedbacks are discussed in Topic 2.3. {WGI 7.3, 10.5, SPM}

Because understanding of some important effects driving sea level rise is too limited, this report does not assess the likelihood, nor provide a best estimate or an upper bound for sea level rise. Model-based projections of global average sea level rise at the end of the 21st century (2090-2099) are shown in Table 3.1. For each scenario, the mid-point of the range in Table 3.1 is within 10% of the TAR model average for 2090-2099. The ranges are narrower than in the TAR mainly because of improved information about some uncertainties in the projected contributions.¹² The sea level projections do not include uncertainties in climate-carbon cycle feedbacks nor do they include the full effects of changes in ice sheet flow, because a basis in published literature is lacking. Therefore the upper values of the ranges given are not to be considered upper bounds for sea level rise. The projections include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for 1993-2003, but these flow rates could increase or decrease in the future. If this contribution were to grow linearly with global average temperature change, the upper ranges of sea level rise for SRES scenarios shown in Table 3.1 would increase by 0.1 to 0.2m.¹³ {WGI 10.6, SPM}

Table 3.1. Projected global average surface warming and sea level rise at the end of the 21st century. {WGI 10.5, 10.6, Table 10.7, Table SPM.3}

Case	Temperature change (°C at 2090-2099 relative to 1980-1999) ^{a, d}		Sea level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	Likely range	Model-based range excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations ^b	0.6	0.3 – 0.9	Not available
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Notes:

- These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity, and a large number of Atmosphere-Ocean General Circulation Models (AOGCMs) as well as observational constraints.
- Year 2000 constant composition is derived from AOGCMs only.
- All scenarios above are six SRES marker scenarios. Approximate CO₂-eq concentrations corresponding to the computed radiative forcing due to anthropogenic GHGs and aerosols in 2100 (see p. 823 of the WGI TAR) for the SRES B1, A1T, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1550ppm, respectively.
- Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 add 0.5°C.

¹² TAR projections were made for 2100, whereas the projections for this report are for 2090-2099. The TAR would have had similar ranges to those in Table 3.1 if it had treated uncertainties in the same way.

¹³ For discussion of the longer term see Sections 3.2.3 and 5.2.

3.2.2 21st century regional changes

There is now higher confidence than in the TAR in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation and some aspects of extremes and sea ice. [WGI 8.2, 8.3, 8.4, 8.5, 9.4, 9.5, 10.3, 11.1]

Projected warming in the 21st century shows scenario-independent geographical patterns similar to those observed over the past several decades. Warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean (near Antarctica) and northern North Atlantic, continuing recent observed trends (Figure 3.2 right panels). [WGI 10.3, SPM]

Snow cover area is projected to contract. Widespread increases in thaw depth are projected over most permafrost regions. Sea ice is projected to shrink in both the Arctic and Antarctic under all SRES scenarios. In some projections, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century. [WGI 10.3, 10.6, SPM; WGII 15.3.4]

It is *very likely* that hot extremes, heat waves and heavy precipitation events will become more frequent. [SYR Table 3.2; WGI 10.3, SPM]

Based on a range of models, it is *likely* that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea-surface temperatures. There is less confidence in projections of a global decrease in numbers of tropical cyclones. The apparent increase in the proportion of very

intense storms since 1970 in some regions is much larger than simulated by current models for that period. [WGI 3.8, 9.5, 10.3, SPM]

Extra-tropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation and temperature patterns, continuing the broad pattern of observed trends over the last half-century. [WGI 3.6, 10.3, SPM]

Since the TAR there is an improving understanding of projected patterns of precipitation. Increases in the amount of precipitation are *very likely* in high-latitudes, while decreases are *likely* in most subtropical land regions (by as much as about 20% in the A1B scenario in 2100, Figure 3.3), continuing observed patterns in recent trends. [WGI 3.3, 8.3, 9.5, 10.3, 11.2-11.9, SPM]

3.2.3 Changes beyond the 21st century

Anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if GHG concentrations were to be stabilised. [WGI 10.4, 10.5, 10.7, SPM]

If radiative forcing were to be stabilised, keeping all the radiative forcing agents constant at B1 or A1B levels in 2100, model experiments show that a further increase in global average temperature of about 0.5°C would still be expected by 2200. In addition, thermal expansion alone would lead to 0.3 to 0.8m of sea level rise by 2300 (relative to 1980-1999). Thermal expansion would continue for many centuries, due to the time required to transport heat into the deep ocean. [WGI 10.7, SPM]

Atmosphere-Ocean General Circulation Model projections of surface warming

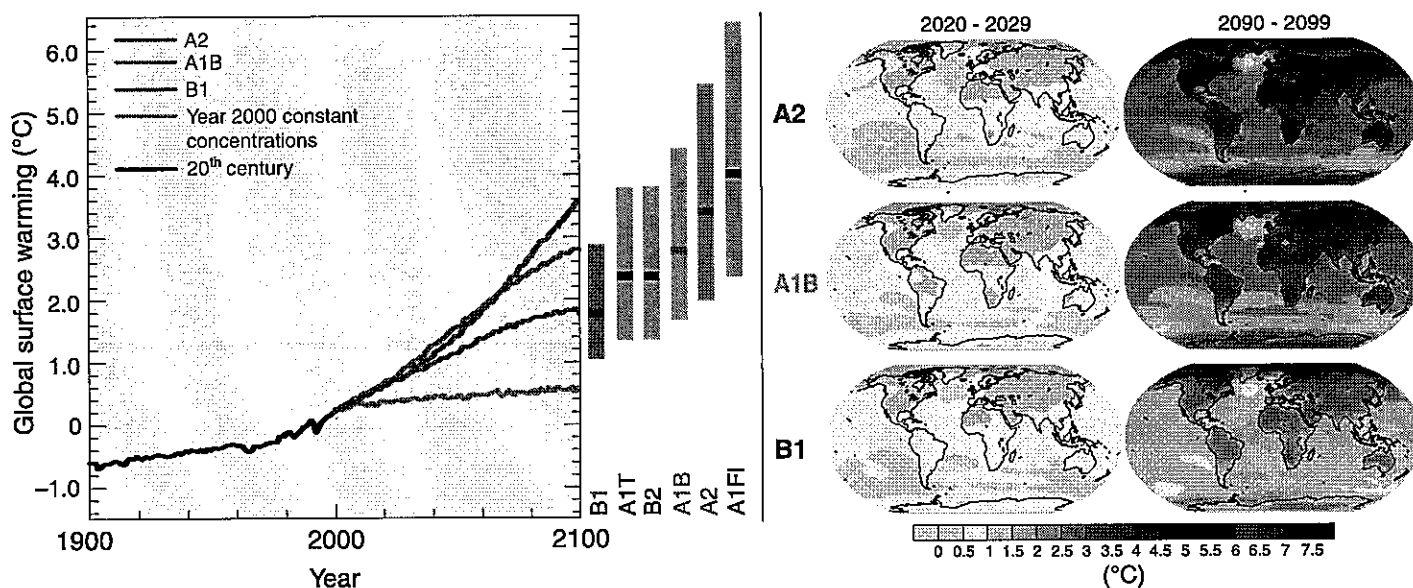


Figure 3.2. Left panel: Solid lines are multi-model global averages of surface warming (relative to 1980-1999) for the SRES scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. The orange line is for the experiment where concentrations were held constant at year 2000 values. The bars in the middle of the figure indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios at 2090-2099 relative to 1980-1999. The assessment of the best estimate and likely ranges in the bars includes the Atmosphere-Ocean General Circulation Models (AOGCMs) in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. Right panels: Projected surface temperature changes for the early and late 21st century relative to the period 1980-1999. The panels show the multi-AOGCM average projections for the A2 (top), A1B (middle) and B1 (bottom) SRES scenarios averaged over decades 2020-2029 (left) and 2090-2099 (right). [WGI 10.4, 10.8, Figures 10.28, 10.29, SPM]

Multi-model projected patterns of precipitation changes

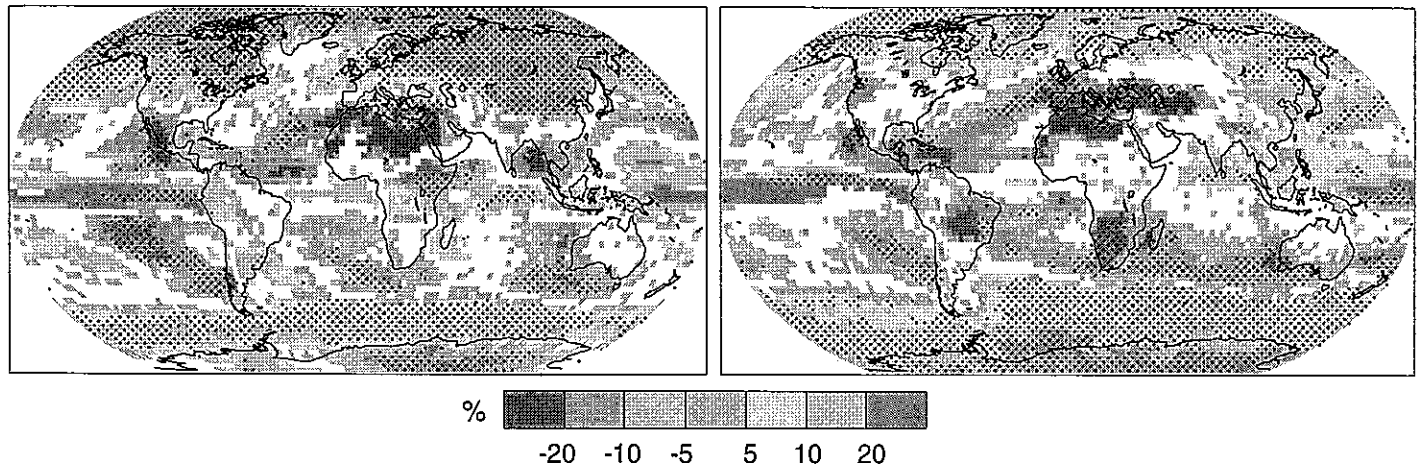


Figure 3.3. Relative changes in precipitation (in percent) for the period 2090-2099, relative to 1980-1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. (WGI Figure 10.9, SPM)

Contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. Current models suggest ice mass losses increase with temperature more rapidly than gains due to increased precipitation and that the surface mass balance becomes negative (net ice loss) at a global average warming (relative to pre-industrial values) in excess of 1.9 to 4.6°C. If such a negative surface mass balance were sustained for millennia, that would lead to virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7m. The corresponding future temperatures in Greenland (1.9 to 4.6°C global) are comparable to those inferred for the last interglacial period 125,000 years ago, when palaeoclimatic information suggests reductions of polar land ice extent and 4 to 6m of sea level rise. (WGI 6.4, 10.7, SPM)

Dynamical processes related to ice flow – which are not included in current models but suggested by recent observations –

could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. Understanding of these processes is limited and there is no consensus on their magnitude. (WGI 4.6, 10.7, SPM)

Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and gain mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance. (WGI 10.7, SPM)

Both past and future anthropogenic CO₂ emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the time scales required for the removal of this gas from the atmosphere. (WGI 7.3, 10.3, Figure 7.12, Figure 10.35, SPM)

Estimated long-term (multi-century) warming corresponding to the six AR4 WG III stabilisation categories is shown in Figure 3.4.

Estimated multi-century warming relative to 1980-1999 for AR4 stabilisation categories

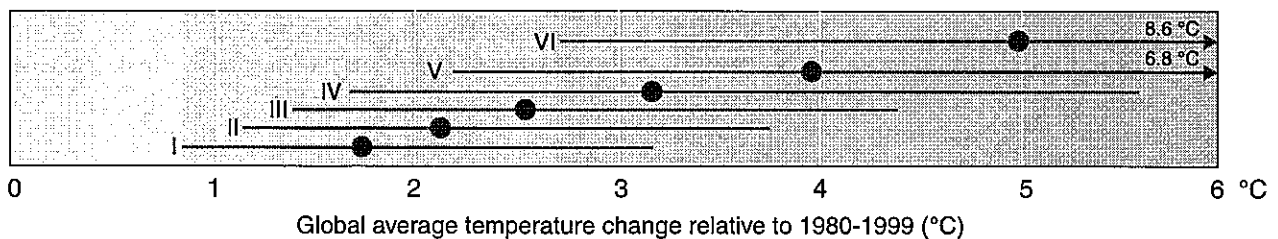


Figure 3.4. Estimated long-term (multi-century) warming corresponding to the six AR4 WG III stabilisation categories (Table 5.1). The temperature scale has been shifted by -0.5°C compared to Table 5.1 to account approximately for the warming between pre-industrial and 1980-1999. For most stabilisation levels global average temperature is approaching the equilibrium level over a few centuries. For GHG emissions scenarios that lead to stabilisation at levels comparable to SRES B1 and A1B by 2100 (600 and 850 ppm CO₂-eq; category IV and V), assessed models project that about 65 to 70% of the estimated global equilibrium temperature increase, assuming a climate sensitivity of 3°C, would be realised at the time of stabilisation. For the much lower stabilisation scenarios (category I and II, Figure 5.1), the equilibrium temperature may be reached earlier. (WGI 10.7.2)

3.3 Impacts of future climate changes

More specific information is now available across a wide range of systems and sectors concerning the nature of future impacts, including some fields not covered in previous assessments. *{WGII TS.4, SPM}*

The following is a selection of key findings¹⁴ regarding the impacts of climate change on systems, sectors and regions, as well as some findings on vulnerability¹⁵, for the range of climate changes projected over the 21st century. Unless otherwise stated, the confidence level in the projections is *high*. Global average temperature increases are given relative to 1980-1999. Additional information on impacts can be found in the WG II report. *{WGII SPM}*

3.3.1 Impacts on systems and sectors

Ecosystems

- The resilience of many ecosystems is *likely* to be exceeded this century by an unprecedented combination of climate change, associated disturbances (e.g. flooding, drought, wildfire, insects, ocean acidification) and other global change drivers (e.g. land-use change, pollution, fragmentation of natural systems, over-exploitation of resources). *{WGII 4.1-4.6, SPM}*
- Over the course of this century, net carbon uptake by terrestrial ecosystems is *likely* to peak before mid-century and then weaken or even reverse¹⁶, thus amplifying climate change. *{WGII 4.ES, Figure 4.2, SPM}*
- Approximately 20 to 30% of plant and animal species assessed so far are *likely* to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5°C (*medium confidence*). *{WGII 4.ES, Figure 4.2, SPM}*
- For increases in global average temperature exceeding 1.5 to 2.5°C and in concomitant atmospheric CO₂ concentrations, there are projected to be major changes in ecosystem structure and function, species' ecological interactions and shifts in species' geographical ranges, with predominantly negative consequences for biodiversity and ecosystem goods and services, e.g. water and food supply. *{WGII 4.4, Box TS.6, SPM}*

Food

- Crop productivity is projected to increase slightly at mid- to high latitudes for local mean temperature increases of up to 1 to 3°C depending on the crop, and then decrease beyond that in some regions (*medium confidence*). *{WGII 5.4, SPM}*
- At lower latitudes, especially in seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1 to 2°C), which would increase the risk of hunger (*medium confidence*). *{WGII 5.4, SPM}*
- Globally, the potential for food production is projected to increase with increases in local average temperature over a range

of 1 to 3°C, but above this it is projected to decrease (*medium confidence*). *{WGII 5.4, 5.5, SPM}*

Coasts

- Coasts are projected to be exposed to increasing risks, including coastal erosion, due to climate change and sea level rise. The effect will be exacerbated by increasing human-induced pressures on coastal areas (*very high confidence*). *{WGII 6.3, 6.4, SPM}*
- By the 2080s, many millions more people than today are projected to experience floods every year due to sea level rise. The numbers affected will be largest in the densely populated and low-lying megadeltas of Asia and Africa while small islands are especially vulnerable (*very high confidence*). *{WGII 6.4, 6.5, Table 6.11, SPM}*

Industry, settlements and society

- The most vulnerable industries, settlements and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources and those in areas prone to extreme weather events, especially where rapid urbanisation is occurring. *{WGII 7.1, 7.3, 7.4, 7.5, SPM}*
- Poor communities can be especially vulnerable, in particular those concentrated in high-risk areas. *{WGII 7.2, 7.4, 5.4, SPM}*

Health

- The health status of millions of people is projected to be affected through, for example, increases in malnutrition; increased deaths, diseases and injury due to extreme weather events; increased burden of diarrhoeal diseases; increased frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone in urban areas related to climate change; and the altered spatial distribution of some infectious diseases. *{WGI 7.4, Box 7.4; WGII 8.ES, 8.2, 8.4, SPM}*
- Climate change is projected to bring some benefits in temperate areas, such as fewer deaths from cold exposure, and some mixed effects such as changes in range and transmission potential of malaria in Africa. Overall it is expected that benefits will be outweighed by the negative health effects of rising temperatures, especially in developing countries. *{WGII 8.4, 8.7, 8.ES, SPM}*
- Critically important will be factors that directly shape the health of populations such as education, health care, public health initiatives, and infrastructure and economic development. *{WGII 8.3, SPM}*

Water

- Water impacts are key for all sectors and regions. These are discussed below in the Box 'Climate change and water'.

¹⁴ Criteria of choice: magnitude and timing of impact, confidence in the assessment, representative coverage of the system, sector and region.

¹⁵ Vulnerability to climate change is the degree to which systems are susceptible to, and unable to cope with, adverse impacts.

¹⁶ Assuming continued GHG emissions at or above current rates and other global changes including land-use changes.

Climate change and water

Climate change is expected to exacerbate current stresses on water resources from population growth and economic and land-use change, including urbanisation. On a regional scale, mountain snow pack, glaciers and small ice caps play a crucial role in freshwater availability. Widespread mass losses from glaciers and reductions in snow cover over recent decades are projected to accelerate throughout the 21st century, reducing water availability, hydropower potential, and changing seasonality of flows in regions supplied by meltwater from major mountain ranges (e.g. Hindu-Kush, Himalaya, Andes), where more than one-sixth of the world population currently lives. [WGI 4.1, 4.5; WGII 3.3, 3.4, 3.5]

Changes in precipitation (Figure 3.3) and temperature (Figure 3.2) lead to changes in runoff (Figure 3.5) and water availability. Runoff is projected with *high confidence* to increase by 10 to 40% by mid-century at higher latitudes and in some wet tropical areas, including populous areas in East and South-East Asia, and decrease by 10 to 30% over some dry regions at mid-latitudes and dry tropics, due to decreases in rainfall and higher rates of evapotranspiration. There is also *high confidence* that many semi-arid areas (e.g. the Mediterranean Basin, western United States, southern Africa and north-eastern Brazil) will suffer a decrease in water resources due to climate change. Drought-affected areas are projected to increase in extent, with the potential for adverse impacts on multiple sectors, e.g. agriculture, water supply, energy production and health. Regionally, large increases in irrigation water demand as a result of climate changes are projected. [WGI 10.3, 11.2-11.9; WGII 3.4, 3.5, Figure 3.5, TS.4.1, Box TS.5, SPM]

The negative impacts of climate change on freshwater systems outweigh its benefits (*high confidence*). Areas in which runoff is projected to decline face a reduction in the value of the services provided by water resources (*very high confidence*). The beneficial impacts of increased annual runoff in some areas are *likely* to be tempered by negative effects of increased precipitation variability and seasonal runoff shifts on water supply, water quality and flood risk. [WGII 3.4, 3.5, TS.4.1]

Available research suggests a significant future increase in heavy rainfall events in many regions, including some in which the mean rainfall is projected to decrease. The resulting increased flood risk poses challenges to society, physical infrastructure and water quality. It is *likely* that up to 20% of the world population will live in areas where river flood potential could increase by the 2080s. Increases in the frequency and severity of floods and droughts are projected to adversely affect sustainable development. Increased temperatures will further affect the physical, chemical and biological properties of freshwater lakes and rivers, with predominantly adverse impacts on many individual freshwater species, community composition and water quality. In coastal areas, sea level rise will exacerbate water resource constraints due to increased salinisation of groundwater supplies. [WGI 11.2-11.9; WGII 3.2, 3.3, 3.4, 4.4]

Projections and model consistency of relative changes in runoff by the end of the 21st century

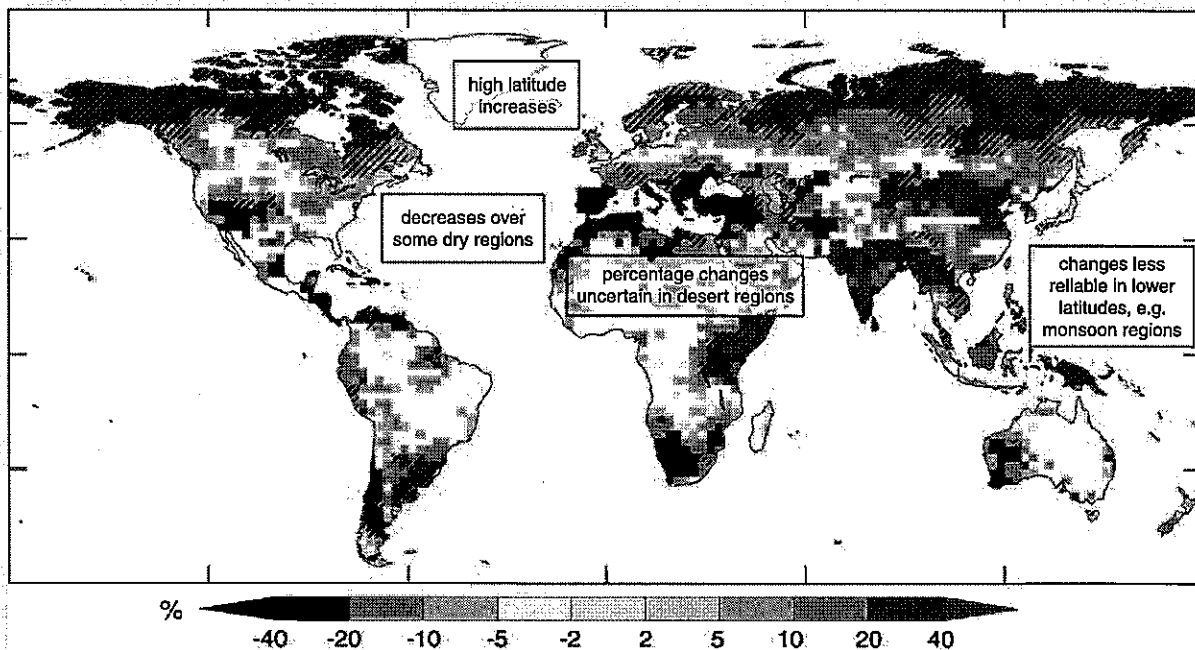


Figure 3.5. Large-scale relative changes in annual runoff (water availability, in percent) for the period 2090-2099, relative to 1980-1999. Values represent the median of 12 climate models using the SRES A1B scenario. White areas are where less than 66% of the 12 models agree on the sign of change and hatched areas are where more than 90% of models agree on the sign of change. The quality of the simulation of the observed large-scale 20th century runoff is used as a basis for selecting the 12 models from the multi-model ensemble. The global map of annual runoff illustrates a large scale and is not intended to refer to smaller temporal and spatial scales. In areas where rainfall and runoff is very low (e.g. desert areas), small changes in runoff can lead to large percentage changes. In some regions, the sign of projected changes in runoff differs from recently observed trends. In some areas with projected increases in runoff, different seasonal effects are expected, such as increased wet season runoff and decreased dry season runoff. Studies using results from few climate models can be considerably different from the results presented here. [WGII Figure 3.4, adjusted to match the assumptions of Figure SYR 3.3; WGII 3.3.1, 3.4.1, 3.5.1]

Studies since the TAR have enabled more systematic understanding of the timing and magnitude of impacts related to differing amounts and rates of climate change. *{WGII SPM}*

Examples of this new information for systems and sectors are presented in Figure 3.6. The upper panel shows impacts increasing with increasing temperature change. Their estimated magnitude and timing is also affected by development pathways (lower panel). *{WGII SPM}*

Depending on circumstances, some of the impacts shown in Figure 3.6 could be associated with ‘key vulnerabilities’, based on a number of criteria in the literature (magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and ‘importance’ of the impacts) (see Topic 5.2). *{WGII SPM}*

3.3.2 Impacts on regions¹⁷

Africa

- By 2020, between 75 and 250 million of people are projected to be exposed to increased water stress due to climate change. *{WGII 9.4, SPM}*
- By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition. *{WGII 9.4, SPM}*
- Towards the end of the 21st century, projected sea level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5 to 10% of GDP. *{WGII 9.4, SPM}*
- By 2080, an increase of 5 to 8% of arid and semi-arid land in Africa is projected under a range of climate scenarios (*high confidence*). *{WGII Box TS.6, 9.4.4}*

Asia

- By the 2050s, freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease. *{WGII 10.4, SPM}*
- Coastal areas, especially heavily populated megadelta regions in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, flooding from the rivers. *{WGII 10.4, SPM}*
- Climate change is projected to compound the pressures on natural resources and the environment associated with rapid urbanisation, industrialisation and economic development. *{WGII 10.4, SPM}*
- Endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts are expected to rise in East, South and South-East Asia due to projected changes in the hydrological cycle. *{WGII 10.4, SPM}*

Australia and New Zealand

- By 2020, significant loss of biodiversity is projected to occur in some ecologically rich sites, including the Great Barrier Reef and Queensland Wet Tropics. *{WGII 11.4, SPM}*

- By 2030, water security problems are projected to intensify in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions. *{WGII 11.4, SPM}*
- By 2030, production from agriculture and forestry is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits are projected in some other regions. *{WGII 11.4, SPM}*
- By 2050, ongoing coastal development and population growth in some areas of Australia and New Zealand are projected to exacerbate risks from sea level rise and increases in the severity and frequency of storms and coastal flooding. *{WGII 11.4, SPM}*

Europe

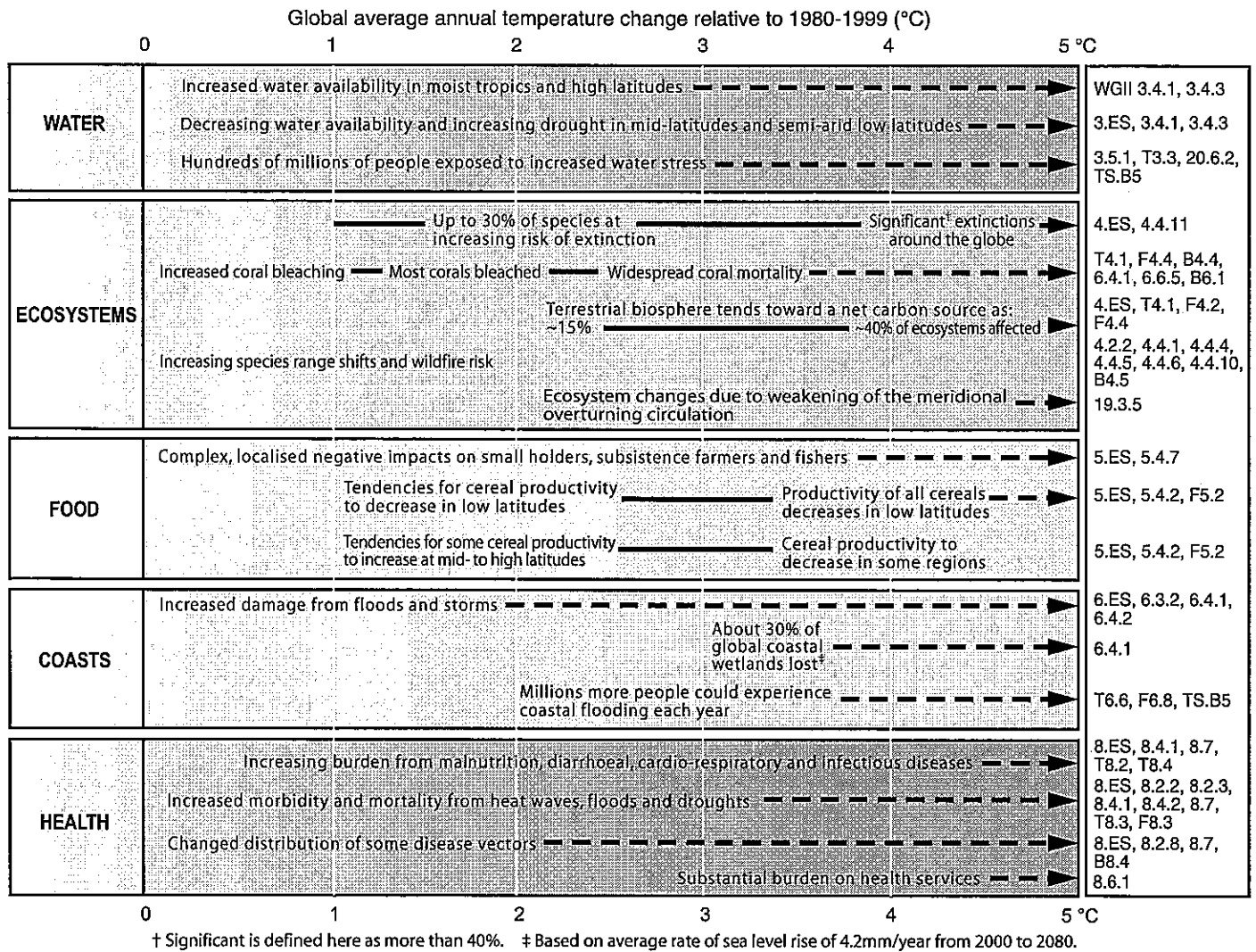
- Climate change is expected to magnify regional differences in Europe’s natural resources and assets. Negative impacts will include increased risk of inland flash floods and more frequent coastal flooding and increased erosion (due to storminess and sea level rise). *{WGII 12.4, SPM}*
- Mountainous areas will face glacier retreat, reduced snow cover and winter tourism, and extensive species losses (in some areas up to 60% under high emissions scenarios by 2080). *{WGII 12.4, SPM}*
- In southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism and, in general, crop productivity. *{WGII 12.4, SPM}*
- Climate change is also projected to increase the health risks due to heat waves and the frequency of wildfires. *{WGII 12.4, SPM}*

Latin America

- By mid-century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation. *{WGII 13.4, SPM}*
- There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America. *{WGII 13.4, SPM}*
- Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones, soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase (*medium confidence*). *{WGII 13.4, Box TS.6}*
- Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation. *{WGII 13.4, SPM}*

¹⁷ Unless stated explicitly, all entries are from WG II SPM text, and are either *very high confidence* or *high confidence* statements, reflecting different sectors (agriculture, ecosystems, water, coasts, health, industry and settlements). The WG II SPM refers to the source of the statements, timelines and temperatures. The magnitude and timing of impacts that will ultimately be realised will vary with the amount and rate of climate change, emissions scenarios, development pathways and adaptation.

Examples of impacts associated with global average temperature change
 (Impacts will vary by extent of adaptation, rate of temperature change and socio-economic pathway)



Warming by 2090-2099 relative to 1980-1999 for non-mitigation scenarios

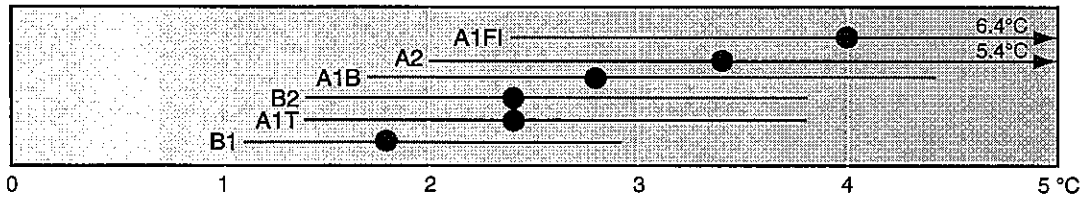


Figure 3.6. Examples of impacts associated with global average temperature change. **Upper panel:** Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO₂ where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. The black lines link impacts; broken-line arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left-hand side of text indicates the approximate level of warming that is associated with the onset of a given impact. Quantitative entries for water scarcity and flooding represent the additional impacts of climate change relative to the conditions projected across the range of SRES scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. Confidence levels for all statements are high. The upper right panel gives the WG II references for the statements made in the upper left panel.* **Lower panel:** Dots and bars indicate the best estimate and likely ranges of warming assessed for the six SRES marker scenarios for 2090-2099 relative to 1980-1999. {WGI Figure SPM.5, 10.7; WGII Figure SPM.2; WGIII Table TS.2, Table 3.10}

*Where ES = Executive Summary, T = Table, B = Box and F = Figure. Thus B4.5 indicates Box 4.5 in Chapter 4 and 3.5.1 indicates Section 3.5.1 in Chapter 3.

North America

- Warming in western mountains is projected to cause decreased snowpack, more winter flooding and reduced summer flows, exacerbating competition for over-allocated water resources. *{WGII 14.4, SPM}*
- In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5 to 20%, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilised water resources. *{WGII 14.4, SPM}*
- Cities that currently experience heat waves are expected to be further challenged by an increased number, intensity and duration of heat waves during the course of the century, with potential for adverse health impacts. *{WGII 14.4, SPM}*
- Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution. *{WGII 14.4, SPM}*

Polar Regions

- The main projected biophysical effects are reductions in thickness and extent of glaciers, ice sheets and sea ice, and changes in natural ecosystems with detrimental effects on many organisms including migratory birds, mammals and higher predators. *{WGII 15.4, SPM}*
- For human communities in the Arctic, impacts, particularly those resulting from changing snow and ice conditions, are projected to be mixed. *{WGII 15.4, SPM}*
- Detrimental impacts would include those on infrastructure and traditional indigenous ways of life. *{WGII 15.4, SPM}*
- In both polar regions, specific ecosystems and habitats are projected to be vulnerable, as climatic barriers to species invasions are lowered. *{WGII 15.4, SPM}*

Small Islands

- Sea level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities. *{WGII 16.4, SPM}*
- Deterioration in coastal conditions, for example through erosion of beaches and coral bleaching, is expected to affect local resources. *{WGII 16.4, SPM}*
- By mid-century, climate change is expected to reduce water resources in many small islands, e.g. in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low-rainfall periods. *{WGII 16.4, SPM}*
- With higher temperatures, increased invasion by non-native species is expected to occur, particularly on mid- and high-latitude islands. *{WGII 16.4, SPM}*

3.3.3 Especially affected systems, sectors and regions

Some systems, sectors and regions are *likely* to be especially affected by climate change.¹⁸ *{WGII TS.4.5}*

Systems and sectors: *{WGII TS.4.5}*

- particular ecosystems:
 - terrestrial: tundra, boreal forest and mountain regions because of sensitivity to warming; mediterranean-type ecosystems because of reduction in rainfall; and tropical rainforests where precipitation declines
 - coastal: mangroves and salt marshes, due to multiple stresses
 - marine: coral reefs due to multiple stresses; the sea-ice biome because of sensitivity to warming
- water resources in some dry regions at mid-latitudes¹⁹ and in the dry tropics, due to changes in rainfall and evapotranspiration, and in areas dependent on snow and ice melt
- agriculture in low latitudes, due to reduced water availability
- low-lying coastal systems, due to threat of sea level rise and increased risk from extreme weather events
- human health in populations with low adaptive capacity.

Regions: *{WGII TS.4.5}*

- the Arctic, because of the impacts of high rates of projected warming on natural systems and human communities
- Africa, because of low adaptive capacity and projected climate change impacts
- small islands, where there is high exposure of population and infrastructure to projected climate change impacts
- Asian and African megadeltas, due to large populations and high exposure to sea level rise, storm surges and river flooding.

Within other areas, even those with high incomes, some people (such as the poor, young children and the elderly) can be particularly at risk, and also some areas and some activities. *{WGII 7.1, 7.2, 7.4, 8.2, 8.4, TS.4.5}*

3.3.4 Ocean acidification

The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic with an average decrease in pH of 0.1 units. Increasing atmospheric CO₂ concentrations lead to further acidification. Projections based on SRES scenarios give a reduction in average global surface ocean pH of between 0.14 and 0.35 units over the 21st century. While the effects of observed ocean acidification on the marine biosphere are as yet undocumented, the progressive acidification of oceans is expected to have negative impacts on marine shell-forming organisms (e.g. corals) and their dependent species. *{WGI SPM; WGII SPM}*

3.3.5 Extreme events

Altered frequencies and intensities of extreme weather, together with sea level rise, are expected to have mostly adverse effects on natural and human systems (Table 3.2). *{WGII SPM}*

Examples for selected extremes and sectors are shown in Table 3.2.

¹⁸ Identified on the basis of expert judgement of the assessed literature and considering the magnitude, timing and projected rate of climate change, sensitivity and adaptive capacity.

¹⁹ Including arid and semi-arid regions.

Table 3.2. Examples of possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid- to late 21st century. These do not take into account any changes or developments in adaptive capacity. The likelihood estimates in column two relate to the phenomena listed in column one. {WGII Table SPM.1}

Phenomenon ^a and direction of trend	Likelihood of future trends based on projections for 21 st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems {WGII 4.4, 5.4}	Water resources {WGII 3.4}	Human health {WGII 8.2, 8.4}	Industry, settlement and society {WGII 7.4}
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	<i>Virtually certain^b</i>	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snowmelt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	<i>Very likely</i>	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems, e.g. algal blooms	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over most areas	<i>Very likely</i>	Damage to crops; soil erosion; inability to cultivate land due to waterlogging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	<i>Likely</i>	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	Water shortage for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity increases	<i>Likely</i>	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers; potential for population migrations; loss of property
Increased incidence of extreme high sea level (excludes tsunamis) ^c	<i>Likely^d</i>	Salinisation of irrigation water, estuaries and fresh-water systems	Decreased fresh-water availability due to saltwater intrusion	Increased risk of deaths and injuries by drowning in floods; migration-related health effects	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above

Notes:

- See WGI Table 3.7 for further details regarding definitions.
- Warming of the most extreme days and nights each year.
- Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period.
- In all scenarios, the projected global average sea level at 2100 is higher than in the reference period. The effect of changes in regional weather systems on sea level extremes has not been assessed. {WGI 10.6}

3.4 Risk of abrupt or irreversible changes

Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change. {WGII 12.6, 19.3, 19.4, SPM}

Abrupt climate change on decadal time scales is normally thought of as involving ocean circulation changes. In addition on

longer time scales, ice sheet and ecosystem changes may also play a role. If a large-scale abrupt climate change were to occur, its impact could be quite high (see Topic 5.2). {WGI 8.7, 10.3, 10.7; WGII 4.4, 19.3}

Partial loss of ice sheets on polar land and/or the thermal expansion of seawater over very long time scales could imply metres of sea level rise, major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas and low-lying

islands. Current models project that such changes would occur over very long time scales (millennial) if a global temperature increase of 1.9 to 4.6°C (relative to pre-industrial) were to be sustained. Rapid sea level rise on century time scales cannot be excluded. *{SYR 3.2.3; WGI 6.4, 10.7; WGII 19.3, SPM}*

Climate change is *likely* to lead to some irreversible impacts. There is *medium confidence* that approximately 20 to 30% of species assessed so far are *likely* to be at increased risk of extinction if increases in global average warming exceed 1.5 to 2.5°C (relative to 1980-1999). As global average temperature increase exceeds about 3.5°C, model projections suggest significant extinctions (40 to 70% of species assessed) around the globe. *{WGII 4.4, Figure SPM.2}*

Based on current model simulations, it is *very likely* that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century; nevertheless temperatures in the region are projected to increase. It is *very unlikely* that the MOC will undergo a large abrupt transition during the 21st century. Longer-term changes in the MOC cannot be assessed with confidence. *{WGI 10.3, 10.7; WGII Figure, Table TS.5, SPM.2}*

Impacts of large-scale and persistent changes in the MOC are *likely* to include changes in marine ecosystem productivity, fisheries, ocean CO₂ uptake, oceanic oxygen concentrations and terrestrial vegetation. Changes in terrestrial and ocean CO₂ uptake may feed back on the climate system. *{WGII 12.6, 19.3, Figure SPM.2}*

4

**Adaptation and mitigation options and responses,
and the inter-relationship with sustainable
development, at global and regional levels**

4.1 Responding to climate change

Societies can respond to climate change by adapting to its impacts and by reducing GHG emissions (mitigation), thereby reducing the rate and magnitude of change. This Topic focuses on adaptation and mitigation options that can be implemented over the next two to three decades, and their inter-relationship with sustainable development. These responses can be complementary. Topic 5 addresses their complementary roles on a more conceptual basis over a longer timeframe.

The capacity to adapt and mitigate is dependent on socio-economic and environmental circumstances and the availability of information and technology²⁰. However, much less information is available about the costs and effectiveness of adaptation measures than about mitigation measures. *{WGII 17.1, 17.3; WGIII 1.2}*

4.2 Adaptation options

Adaptation can reduce vulnerability, both in the short and the long term. *{WGII 17.2, 18.1, 18.5, 20.3, 20.8}*

Vulnerability to climate change can be exacerbated by other stresses. These arise from, for example, current climate hazards, poverty, unequal access to resources, food insecurity, trends in economic globalisation, conflict and incidence of diseases such as HIV/AIDS. *{WGII 7.2, 7.4, 8.3, 17.3, 20.3, 20.4, 20.7, SPM}*

Societies across the world have a long record of adapting and reducing their vulnerability to the impacts of weather- and climate-related events such as floods, droughts and storms. Nevertheless, additional adaptation measures will be required at regional and local levels to reduce the adverse impacts of projected climate change and variability, regardless of the scale of mitigation undertaken over the next two to three decades. However, adaptation alone is not expected to cope with all the projected effects of climate change, especially not over the long term as most impacts increase in magnitude. *{WGII 17.2, SPM; WGIII 1.2}*

A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to climate change. There are barriers, limits and costs, which are not fully understood. Some planned adaptation is already occurring on a limited basis. Table 4.1 provides examples of planned

adaptation options by sector. Many adaptation actions have multiple drivers, such as economic development and poverty alleviation, and are embedded within broader development, sectoral, regional and local planning initiatives such as water resources planning, coastal defence and disaster risk reduction strategies. Examples of this approach are the Bangladesh National Water Management Plan and the coastal defence plans of The Netherlands and Norway, which incorporate specific climate change scenarios. *{WGII 1.3, 5.5.2, 11.6, 17.2}*

Comprehensive estimates of the costs and benefits of adaptation at the global level are limited in number. However, the number of adaptation cost and benefit estimates at the regional and project levels for impacts on specific sectors, such as agriculture, energy demand for heating and cooling, water resources management and infrastructure, is growing. Based on these studies there is *high confidence* that there are viable adaptation options that can be implemented in some of these sectors at low cost and/or with high benefit-cost ratios. Empirical research also suggests that higher benefit-cost ratios can be achieved by implementing some adaptation measures at an early stage compared to retrofitting long-lived infrastructure at a later date. *{WGII 17.2}*

Adaptive capacity is intimately connected to social and economic development, but it is not evenly distributed across and within societies. *{WGII 7.1, 7.2, 7.4, 17.3}*

The capacity to adapt is dynamic and is influenced by a society's productive base, including natural and man-made capital assets, social networks and entitlements, human capital and institutions, governance, national income, health and technology. It is also affected by multiple climate and non-climate stresses, as well as development policy. *{WGII 17.3}*

Recent studies reaffirm the TAR finding that adaptation will be vital and beneficial. However, financial, technological, cognitive, behavioural, political, social, institutional and cultural constraints limit both the implementation and effectiveness of adaptation measures. Even societies with high adaptive capacity remain vulnerable to climate change, variability and extremes. For example, a heat wave in 2003 caused high levels of mortality in European cities (especially among the elderly), and Hurricane Katrina in 2005 caused large human and financial costs in the United States. *{WGII 7.4, 8.2, 17.4}*

²⁰ Technology is defined as the practical application of knowledge to achieve particular tasks that employs both technical artefacts (hardware, equipment) and (social) information ('software', know-how for production and use of artefacts).

Table 4.1. Selected examples of planned adaptation by sector.

Sector	Adaptation option/strategy	Underlying policy framework	Key constraints and opportunities to implementation (Normal font = constraints; <i>italics = opportunities</i>)
<p>Water (WGII 5.5, 16.4; Tables 3.5, 11.6, 17.1)</p>	<p>Expanded rainwater harvesting; water storage and conservation techniques; water reuse, desalination, water-use and irrigation efficiency</p>	<p>National water policies and integrated water resources management; water-related hazards management</p>	<p>Financial, human resources and physical barriers; <i>integrated water resources management; synergies with other sectors</i></p>
<p>Agriculture (WGII 10.5, 13.5; Table 10.8)</p>	<p>Adjustment of planting dates and crop variety; crop relocation; improved land management; e.g. erosion control and soil protection through tree planting</p>	<p>R&D policies; institutional reform; land tenure and land reform; training; capacity building; crop insurance; financial incentives, e.g. subsidies and tax credits</p>	<p>Technological and financial constraints; access to new varieties; markets; <i>longer growing season in higher latitudes; revenues from 'new' products</i></p>
<p>Infrastructure/settlement (including coastal zones) (WGII 3.6, 11.4; Tables 6.11, 17.1)</p>	<p>Relocation; seawalls and storm surge barriers; dune reinforcement; land acquisition and creation of marshlands/wetlands as buffer against sea level rise and flooding; protection of existing natural barriers</p>	<p>Standards and regulations that integrate climate change considerations into design; land-use policies; building codes; insurance</p>	<p>Financial and technological barriers; availability of relocation space; <i>integrated policies and management; synergies with sustainable development goals</i></p>
<p>Human health (WGII 14.5; Table 10.8)</p>	<p>Heat-health action plans; emergency medical services; improved climate-sensitive disease surveillance and control; safe water and improved sanitation</p>	<p>Public health policies that recognise climate risk; strengthen health services; regional and international cooperation</p>	<p>Limits to human tolerance (vulnerable groups); knowledge limitations; financial capacity; <i>upgraded health services; improved quality of life</i></p>
<p>Tourism (WGII 12.5, 15.5, 17.5; Table 17.1)</p>	<p>Diversification of tourism attractions and revenues; shifting ski slopes to higher altitudes and glaciers; artificial snow-making</p>	<p>Integrated planning (e.g. carrying capacity; linkages with other sectors); financial incentives; e.g. subsidies and tax credits</p>	<p>Appeal/marketing of new attractions; financial and logistical challenges; potential adverse impact on other sectors (e.g. artificial snow-making may increase energy use); <i>revenues from 'new' attractions; involvement of wider group of stakeholders</i></p>
<p>Transport (WGII 7.6, 17.2)</p>	<p>Realignment/relocation; design standards and planning for roads, rail and other infrastructure to cope with warming and drainage</p>	<p>Integrating climate change considerations into national transport policy; investment in R&D for special situations, e.g. permafrost areas</p>	<p>Financial and technological barriers; availability of less vulnerable routes; <i>improved technologies and integration with key sectors (e.g. energy)</i></p>
<p>Energy (WGII 7.4; 16.2)</p>	<p>Strengthening of overhead transmission and distribution infrastructure; underground cabling for utilities; energy efficiency; use of renewable sources; reduced dependence on single sources of energy</p>	<p>National energy policies; regulations; and fiscal and financial incentives to encourage use of alternative sources; incorporating climate change in design standards</p>	<p>Access to viable alternatives; financial and technological barriers; acceptance of new technologies; <i>stimulation of new technologies; use of local resources</i></p>

Note:
Other examples from many sectors would include early warning systems.

4.3 Mitigation options

Both bottom-up and top-down studies²¹ indicate that there is *high agreement* and *much evidence* of substantial economic potential²¹ for the mitigation of global GHG emissions over the coming decades that could offset the projected growth of global emissions or reduce emissions below current levels. {WGIII 11.3, SPM}

Figure 4.1 compares global economic mitigation potential in 2030 with the projected emissions increase from 2000 to 2030. Bottom-up studies suggest that mitigation opportunities with net negative costs²² have the potential to reduce emissions by about 6 GtCO₂-eq/yr in 2030. Realising these requires dealing with implementation barriers. The economic mitigation potential, which is generally greater than the market mitigation potential, can only be achieved when adequate policies are in place and barriers removed.²¹ {WGIII 11.3, SPM}

Sectoral estimates of economic mitigation potential and marginal costs derived from bottom-up studies corrected for double counting of mitigation potential are shown in Figure 4.2. While top-down and bottom-up studies are in line at the global level, there are considerable differences at the sectoral level. {WGIII 11.3, SPM}

No single technology can provide all of the mitigation potential in any sector. Table 4.2 lists selected examples of key technologies, policies, constraints and opportunities by sector. {WGIII SPM}

Future energy infrastructure investment decisions, expected to total over US\$20 trillion²³ between 2005 and 2030, will have long-term impacts on GHG emissions, because of the long lifetimes of energy plants and other infrastructure capital stock. The widespread diffusion of low-carbon technologies may take many decades, even if early investments in these technologies are made attractive. Initial estimates show that returning global energy-related CO₂ emissions to 2005 levels by 2030 would require a large shift in the pattern of investment, although the net additional investment required ranges from negligible to 5 to 10%. {WGIII 4.1, 4.4, 11.6, SPM}

Comparison between global economic mitigation potential and projected emissions increase in 2030

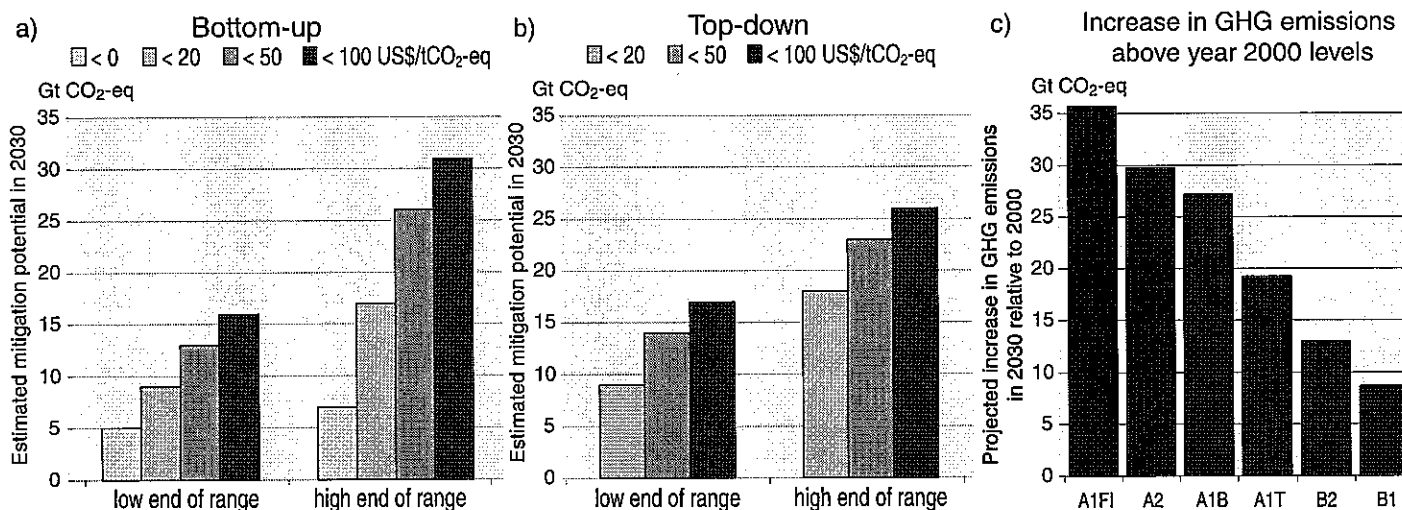


Figure 4.1. Global economic mitigation potential in 2030 estimated from bottom-up (Panel a) and top-down (Panel b) studies, compared with the projected emissions increases from SRES scenarios relative to year 2000 GHG emissions of 40.8 GtCO₂-eq (Panel c). Note: GHG emissions in 2000 are exclusive of emissions of decay of above-ground biomass that remains after logging and deforestation and from peat fires and drained peat soils, to ensure consistency with the SRES emissions results. {WGIII Figures SPM.4, SPM.5a, SPM.5b}

²¹ The concept of 'mitigation potential' has been developed to assess the scale of GHG reductions that could be made, relative to emission baselines, for a given level of carbon price (expressed in cost per unit of carbon dioxide equivalent emissions avoided or reduced). Mitigation potential is further differentiated in terms of 'market mitigation potential' and 'economic mitigation potential'.

Market mitigation potential is the mitigation potential based on private costs and private discount rates (reflecting the perspective of private consumers and companies), which might be expected to occur under forecast market conditions, including policies and measures currently in place, noting that barriers limit actual uptake.

Economic mitigation potential is the mitigation potential that takes into account social costs and benefits and social discount rates (reflecting the perspective of society; social discount rates are lower than those used by private investors), assuming that market efficiency is improved by policies and measures and barriers are removed.

Mitigation potential is estimated using different types of approaches. **Bottom-up studies** are based on assessment of mitigation options, emphasising specific technologies and regulations. They are typically sectoral studies taking the macro-economy as unchanged. **Top-down studies** assess the economy-wide potential of mitigation options. They use globally consistent frameworks and aggregated information about mitigation options and capture macro-economic and market feedbacks.

²² Net negative costs (no regrets opportunities) are defined as those options whose benefits such as reduced energy costs and reduced emissions of local/regional pollutants equal or exceed their costs to society, excluding the benefits of avoided climate change.

²³ 20 trillion = 20,000 billion = 20×10¹²

Economic mitigation potentials by sector in 2030 estimated from bottom-up studies

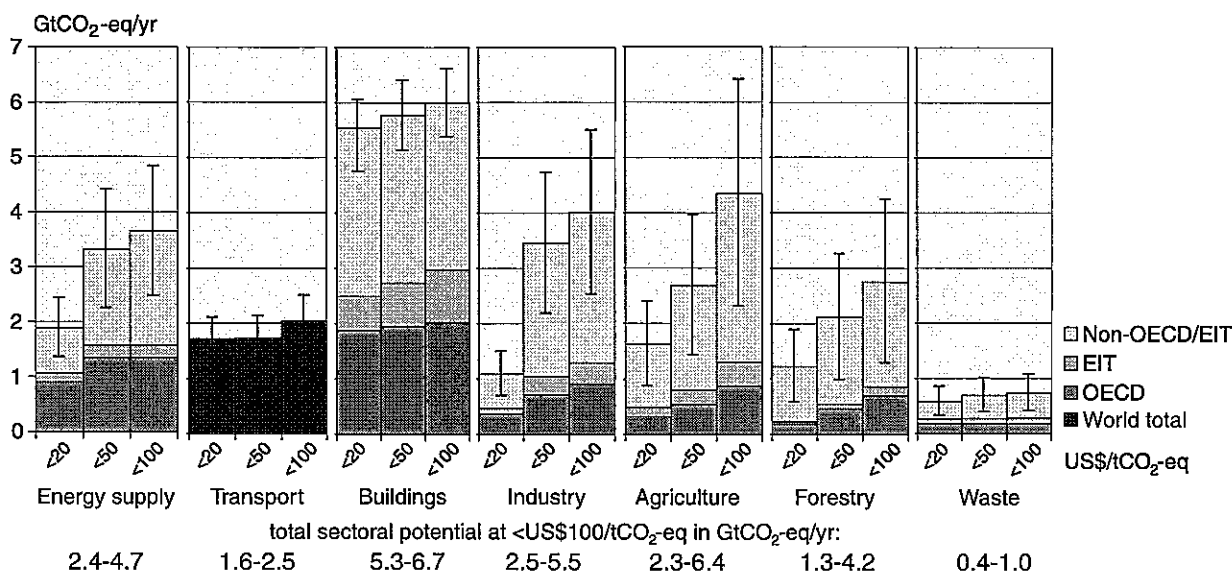


Figure 4.2. Estimated economic mitigation potential by sector and region using technologies and practices expected to be available in 2030. The potentials do not include non-technical options such as lifestyle changes. (WGIII Figure SPM.6)

Notes:

- The ranges for global economic potentials as assessed in each sector are shown by vertical lines. The ranges are based on end-use allocations of emissions, meaning that emissions of electricity use are counted towards the end-use sectors and not to the energy supply sector.
- The estimated potentials have been constrained by the availability of studies particularly at high carbon price levels.
- Sectors used different baselines. For industry the SRES B2 baseline was taken, for energy supply and transport the World Energy Outlook (WEO) 2004 baseline was used; the building sector is based on a baseline in between SRES B2 and A1B; for waste, SRES A1B driving forces were used to construct a waste-specific baseline; agriculture and forestry used baselines that mostly used B2 driving forces.
- Only global totals for transport are shown because international aviation is included.
- Categories excluded are non-CO₂ emissions in buildings and transport, part of material efficiency options, heat production and cogeneration in energy supply, heavy duty vehicles, shipping and high-occupancy passenger transport, most high-cost options for buildings, wastewater treatment, emission reduction from coal mines and gas pipelines, and fluorinated gases from energy supply and transport. The underestimation of the total economic potential from these emissions is of the order of 10 to 15%.

While studies use different methodologies, there is **high agreement** and **much evidence** that in all analysed world regions near-term health co-benefits from reduced air pollution, as a result of actions to reduce GHG emissions, can be substantial and may offset a substantial fraction of mitigation costs. (WGIII 11.8, SPM)

Energy efficiency and utilisation of renewable energy offer synergies with sustainable development. In least developed countries, energy substitution can lower mortality and morbidity by reducing indoor air pollution, reduce the workload for women and children and decrease the unsustainable use of fuelwood and related deforestation. (WGIII 11.8, 11.9, 12.4)

Literature since the TAR confirms with **high agreement** and **medium evidence** that there may be effects from Annex I countries' action on the global economy and global emissions, although the scale of carbon leakage remains uncertain. (WGIII 11.7, SPM)

Fossil fuel exporting nations (in both Annex I and non-Annex I countries) may expect, as indicated in the TAR, lower demand and prices and lower GDP growth due to mitigation policies. The extent of this spillover depends strongly on assumptions related to policy decisions and oil market conditions. (WGIII 11.7, SPM)

Critical uncertainties remain in the assessment of carbon leakage. Most equilibrium modelling supports the conclusion in the TAR of economy-wide leakage from Kyoto action in the order of 5 to 20%, which would be less if competitive low-emissions technologies were effectively diffused. (WGIII 11.7, SPM)

There is also **high agreement** and **medium evidence** that changes in lifestyle and behaviour patterns can contribute to climate change mitigation across all sectors. Management practices can also have a positive role. (WGIII SPM)

Examples that can have positive impacts on mitigation include changes in consumption patterns, education and training, changes in building occupant behaviour, transport demand management and management tools in industry. (WGIII 4.1, 5.1, 6.7, 7.3, SPM)

Policies that provide a real or implicit price of carbon could create incentives for producers and consumers to significantly invest in low-GHG products, technologies and processes. (WGIII SPM)

An effective carbon-price signal could realise significant mitigation potential in all sectors. Modelling studies show that global carbon prices rising to US\$20-80/tCO₂-eq by 2030 are consistent with stabilisation at around 550ppm CO₂-eq by 2100. For the same

Table 4.2 Selected examples of key sectoral mitigation technologies, policies and measures, constraints and opportunities. {WGIII Tables SPM.3, SPM.7}

Sector	Key mitigation technologies and practices currently commercially available. Key mitigation technologies and practices projected to be commercialised before 2030 shown in <i>italics</i> .	Policies, measures and instruments shown to be environmentally effective	Key constraints or opportunities (Normal font = constraints, <i>italics</i> = opportunities)
Energy Supply (WGIII 4.3, 4.4)	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind, geothermal and biomass); combined heat and power; early applications of carbon dioxide capture and storage (CCS) (e.g. storage of removed CO ₂ from natural gas); CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and wave energy, concentrating solar, and solar photovoltaics	Reduction of fossil fuel subsidies; taxes or carbon charges on fossil fuels Feed-in tariffs for renewable energy technologies; renewable energy obligations; producer subsidies Mandatory fuel economy; biofuel blending, and CO ₂ standards for road transport Taxes on vehicle purchase, registration, use and motor fuels; road and parking pricing Influence mobility needs through land-use regulations and infrastructure planning; investment in attractive public transport facilities and non-motorised forms of transport Appliance standards and labelling Building codes and certification Demand-side management programmes Public sector leadership programmes, including procurement Incentives for energy service companies (ESCOs) Provision of benchmark information; performance standards; subsidies; tax credits Tradable permits Voluntary agreements	Resistance by vested interests may make them difficult to implement <i>May be appropriate to create markets for low-emissions technologies</i> Partial coverage of vehicle fleet may limit effectiveness Effectiveness may drop with higher incomes <i>Particularly appropriate for countries that are building up their transportation systems</i> Periodic revision of standards needed <i>Attractive for new buildings. Enforcement can be difficult</i> Need for regulators so that utilities may profit <i>Government purchasing can expand demand for energy-efficient products</i> <i>Success factor: Access to third party financing</i> <i>May be appropriate to stimulate technology uptake</i> Stability of national policy important in view of international competitiveness Predictable allocation mechanisms and stable price signals important for investments Success factors include: clear targets, a baseline scenario, third-party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry <i>May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation</i> Constraints include lack of investment capital and land tenure issues. <i>Can help poverty alleviation.</i> <i>May stimulate technology diffusion</i> Local availability of low-cost fuel Most effectively applied at national level with enforcement strategies
Transport (WGIII 5.4)	More fuel-efficient vehicles; hybrid vehicles, cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land-use and transport planning; second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries	Mandatory fuel economy; biofuel blending, and CO ₂ standards for road transport Taxes on vehicle purchase, registration, use and motor fuels; road and parking pricing Influence mobility needs through land-use regulations and infrastructure planning; investment in attractive public transport facilities and non-motorised forms of transport Appliance standards and labelling Building codes and certification Demand-side management programmes Public sector leadership programmes, including procurement Incentives for energy service companies (ESCOs) Provision of benchmark information; performance standards; subsidies; tax credits Tradable permits Voluntary agreements	Resistance by vested interests may make them difficult to implement <i>May be appropriate to create markets for low-emissions technologies</i> Partial coverage of vehicle fleet may limit effectiveness Effectiveness may drop with higher incomes <i>Particularly appropriate for countries that are building up their transportation systems</i> Periodic revision of standards needed <i>Attractive for new buildings. Enforcement can be difficult</i> Need for regulators so that utilities may profit <i>Government purchasing can expand demand for energy-efficient products</i> <i>Success factor: Access to third party financing</i> <i>May be appropriate to stimulate technology uptake</i> Stability of national policy important in view of international competitiveness Predictable allocation mechanisms and stable price signals important for investments Success factors include: clear targets, a baseline scenario, third-party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry <i>May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation</i> Constraints include lack of investment capital and land tenure issues. <i>Can help poverty alleviation.</i> <i>May stimulate technology diffusion</i> Local availability of low-cost fuel Most effectively applied at national level with enforcement strategies
Buildings (WGIII 6.5)	Efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves; improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids; recovery and recycling of fluorinated gases; integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar photovoltaics integrated in buildings	Mandatory fuel economy; biofuel blending, and CO ₂ standards for road transport Taxes on vehicle purchase, registration, use and motor fuels; road and parking pricing Influence mobility needs through land-use regulations and infrastructure planning; investment in attractive public transport facilities and non-motorised forms of transport Appliance standards and labelling Building codes and certification Demand-side management programmes Public sector leadership programmes, including procurement Incentives for energy service companies (ESCOs) Provision of benchmark information; performance standards; subsidies; tax credits Tradable permits Voluntary agreements	Resistance by vested interests may make them difficult to implement <i>May be appropriate to create markets for low-emissions technologies</i> Partial coverage of vehicle fleet may limit effectiveness Effectiveness may drop with higher incomes <i>Particularly appropriate for countries that are building up their transportation systems</i> Periodic revision of standards needed <i>Attractive for new buildings. Enforcement can be difficult</i> Need for regulators so that utilities may profit <i>Government purchasing can expand demand for energy-efficient products</i> <i>Success factor: Access to third party financing</i> <i>May be appropriate to stimulate technology uptake</i> Stability of national policy important in view of international competitiveness Predictable allocation mechanisms and stable price signals important for investments Success factors include: clear targets, a baseline scenario, third-party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry <i>May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation</i> Constraints include lack of investment capital and land tenure issues. <i>Can help poverty alleviation.</i> <i>May stimulate technology diffusion</i> Local availability of low-cost fuel Most effectively applied at national level with enforcement strategies
Industry (WGIII 7.5)	More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non-CO ₂ gas emissions; and a wide array of process-specific technologies: advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture	Mandatory fuel economy; biofuel blending, and CO ₂ standards for road transport Taxes on vehicle purchase, registration, use and motor fuels; road and parking pricing Influence mobility needs through land-use regulations and infrastructure planning; investment in attractive public transport facilities and non-motorised forms of transport Appliance standards and labelling Building codes and certification Demand-side management programmes Public sector leadership programmes, including procurement Incentives for energy service companies (ESCOs) Provision of benchmark information; performance standards; subsidies; tax credits Tradable permits Voluntary agreements	Resistance by vested interests may make them difficult to implement <i>May be appropriate to create markets for low-emissions technologies</i> Partial coverage of vehicle fleet may limit effectiveness Effectiveness may drop with higher incomes <i>Particularly appropriate for countries that are building up their transportation systems</i> Periodic revision of standards needed <i>Attractive for new buildings. Enforcement can be difficult</i> Need for regulators so that utilities may profit <i>Government purchasing can expand demand for energy-efficient products</i> <i>Success factor: Access to third party financing</i> <i>May be appropriate to stimulate technology uptake</i> Stability of national policy important in view of international competitiveness Predictable allocation mechanisms and stable price signals important for investments Success factors include: clear targets, a baseline scenario, third-party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry <i>May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation</i> Constraints include lack of investment capital and land tenure issues. <i>Can help poverty alleviation.</i> <i>May stimulate technology diffusion</i> Local availability of low-cost fuel Most effectively applied at national level with enforcement strategies
Agriculture (WGIII 8.4)	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH ₄ emissions; improved nitrogen fertiliser application techniques to reduce N ₂ O emissions; dedicated nitrogen crops to replace fossil fuel use; improved energy efficiency; improvements of crop yields	Mandatory fuel economy; biofuel blending, and CO ₂ standards for road transport Taxes on vehicle purchase, registration, use and motor fuels; road and parking pricing Influence mobility needs through land-use regulations and infrastructure planning; investment in attractive public transport facilities and non-motorised forms of transport Appliance standards and labelling Building codes and certification Demand-side management programmes Public sector leadership programmes, including procurement Incentives for energy service companies (ESCOs) Provision of benchmark information; performance standards; subsidies; tax credits Tradable permits Voluntary agreements	Resistance by vested interests may make them difficult to implement <i>May be appropriate to create markets for low-emissions technologies</i> Partial coverage of vehicle fleet may limit effectiveness Effectiveness may drop with higher incomes <i>Particularly appropriate for countries that are building up their transportation systems</i> Periodic revision of standards needed <i>Attractive for new buildings. Enforcement can be difficult</i> Need for regulators so that utilities may profit <i>Government purchasing can expand demand for energy-efficient products</i> <i>Success factor: Access to third party financing</i> <i>May be appropriate to stimulate technology uptake</i> Stability of national policy important in view of international competitiveness Predictable allocation mechanisms and stable price signals important for investments Success factors include: clear targets, a baseline scenario, third-party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry <i>May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation</i> Constraints include lack of investment capital and land tenure issues. <i>Can help poverty alleviation.</i> <i>May stimulate technology diffusion</i> Local availability of low-cost fuel Most effectively applied at national level with enforcement strategies
Forestry/forests (WGIII 9.4)	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use; tree species improvement to increase biomass productivity and carbon sequestration; improved remote sensing technologies for analysis of vegetation/soil carbon sequestration potential and mapping land-use change	Mandatory fuel economy; biofuel blending, and CO ₂ standards for road transport Taxes on vehicle purchase, registration, use and motor fuels; road and parking pricing Influence mobility needs through land-use regulations and infrastructure planning; investment in attractive public transport facilities and non-motorised forms of transport Appliance standards and labelling Building codes and certification Demand-side management programmes Public sector leadership programmes, including procurement Incentives for energy service companies (ESCOs) Provision of benchmark information; performance standards; subsidies; tax credits Tradable permits Voluntary agreements	Resistance by vested interests may make them difficult to implement <i>May be appropriate to create markets for low-emissions technologies</i> Partial coverage of vehicle fleet may limit effectiveness Effectiveness may drop with higher incomes <i>Particularly appropriate for countries that are building up their transportation systems</i> Periodic revision of standards needed <i>Attractive for new buildings. Enforcement can be difficult</i> Need for regulators so that utilities may profit <i>Government purchasing can expand demand for energy-efficient products</i> <i>Success factor: Access to third party financing</i> <i>May be appropriate to stimulate technology uptake</i> Stability of national policy important in view of international competitiveness Predictable allocation mechanisms and stable price signals important for investments Success factors include: clear targets, a baseline scenario, third-party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry <i>May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation</i> Constraints include lack of investment capital and land tenure issues. <i>Can help poverty alleviation.</i> <i>May stimulate technology diffusion</i> Local availability of low-cost fuel Most effectively applied at national level with enforcement strategies
Waste (WGIII 10.4)	Landfill CH ₄ recovery; waste incineration with energy recovery; composting of organic waste; controlled wastewater treatment; recycling and waste minimisation; bioconverters and biofilters to optimise CH ₄ oxidation	Mandatory fuel economy; biofuel blending, and CO ₂ standards for road transport Taxes on vehicle purchase, registration, use and motor fuels; road and parking pricing Influence mobility needs through land-use regulations and infrastructure planning; investment in attractive public transport facilities and non-motorised forms of transport Appliance standards and labelling Building codes and certification Demand-side management programmes Public sector leadership programmes, including procurement Incentives for energy service companies (ESCOs) Provision of benchmark information; performance standards; subsidies; tax credits Tradable permits Voluntary agreements	Resistance by vested interests may make them difficult to implement <i>May be appropriate to create markets for low-emissions technologies</i> Partial coverage of vehicle fleet may limit effectiveness Effectiveness may drop with higher incomes <i>Particularly appropriate for countries that are building up their transportation systems</i> Periodic revision of standards needed <i>Attractive for new buildings. Enforcement can be difficult</i> Need for regulators so that utilities may profit <i>Government purchasing can expand demand for energy-efficient products</i> <i>Success factor: Access to third party financing</i> <i>May be appropriate to stimulate technology uptake</i> Stability of national policy important in view of international competitiveness Predictable allocation mechanisms and stable price signals important for investments Success factors include: clear targets, a baseline scenario, third-party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry <i>May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation</i> Constraints include lack of investment capital and land tenure issues. <i>Can help poverty alleviation.</i> <i>May stimulate technology diffusion</i> Local availability of low-cost fuel Most effectively applied at national level with enforcement strategies

stabilisation level, studies since the TAR that take into account induced technological change may lower these price ranges to US\$5-65/tCO₂-eq in 2030.²⁴ (WGIII 3.3, 11.4, 11.5, SPM)

There is high agreement and much evidence that a wide variety of national policies and instruments are available to governments to create the incentives for mitigation action. Their applicability depends on national circumstances and an understanding of their interactions, but experience from implementation in various countries and sectors shows there are advantages and disadvantages for any given instrument. (WGIII 13.2, SPM)

Four main criteria are used to evaluate policies and instruments: environmental effectiveness, cost effectiveness, distributional effects including equity, and institutional feasibility. (WGIII 13.2, SPM)

General findings about the performance of policies are: (WGIII 13.2, SPM)

- **Integrating climate policies in broader development policies** makes implementation and overcoming barriers easier.
- **Regulations and standards** generally provide some certainty about emission levels. They may be preferable to other instruments when information or other barriers prevent producers and consumers from responding to price signals. However, they may not induce innovations and more advanced technologies.
- **Taxes and charges** can set a price for carbon, but cannot guarantee a particular level of emissions. Literature identifies taxes as an efficient way of internalising costs of GHG emissions.
- **Tradable permits** will establish a carbon price. The volume of allowed emissions determines their environmental effectiveness, while the allocation of permits has distributional consequences. Fluctuation in the price of carbon makes it difficult to estimate the total cost of complying with emission permits.
- **Financial incentives** (subsidies and tax credits) are frequently used by governments to stimulate the development and diffusion of new technologies. While economic costs are generally higher than for the instruments listed above, they are often critical to overcome barriers.
- **Voluntary agreements** between industry and governments are politically attractive, raise awareness among stakeholders and have played a role in the evolution of many national policies. The majority of agreements have not achieved significant emissions reductions beyond business as usual. However, some recent agreements, in a few countries, have accelerated the application of best available technology and led to measurable emission reductions.
- **Information instruments** (e.g. awareness campaigns) may positively affect environmental quality by promoting informed choices and possibly contributing to behavioural change, however, their impact on emissions has not been measured yet.

- **Research, development and demonstration (RD&D)** can stimulate technological advances, reduce costs and enable progress toward stabilisation.

Some corporations, local and regional authorities, NGOs and civil groups are adopting a wide variety of voluntary actions. These voluntary actions may limit GHG emissions, stimulate innovative policies and encourage the deployment of new technologies. On their own, they generally have limited impact on national- or regional-level emissions. (WGIII 13.4, SPM)

4.4 Relationship between adaptation and mitigation options and relationship with sustainable development

There is growing understanding of the possibilities to choose and implement climate response options in several sectors to realise synergies and avoid conflicts with other dimensions of sustainable development. (WGIII SPM)

Climate change policies related to energy efficiency and renewable energy are often economically beneficial, improve energy security and reduce local pollutant emissions. Reducing both loss of natural habitat and deforestation can have significant biodiversity, soil and water conservation benefits, and can be implemented in a socially and economically sustainable manner. Forestation and bioenergy plantations can restore degraded land, manage water runoff, retain soil carbon and benefit rural economies, but could compete with food production and may be negative for biodiversity, if not properly designed. (WGII 20.3, 20.8; WGIII 4.5, 9.7, 12.3, SPM)

There is growing evidence that decisions about macro-economic policy, agricultural policy, multilateral development bank lending, insurance practices, electricity market reform, energy security and forest conservation, for example, which are often treated as being apart from climate policy, can significantly reduce emissions (Table 4.3). Similarly, non-climate policies can affect adaptive capacity and vulnerability. (WGII 20.3; WGIII SPM, 12.3)

Both synergies and trade-offs exist between adaptation and mitigation options. (WGII 18.4.3; WGIII 11.9)

Examples of synergies include properly designed biomass production, formation of protected areas, land management, energy use in buildings, and forestry, but synergies are rather limited in other sectors. Potential trade-offs include increased GHG emissions due to increased consumption of energy related to adaptive responses. (WGII 18.4.3, 18.5, 18.7, TS.5.2; WGIII 4.5, 6.9, 8.5, 9.5, SPM)

²⁴ Studies on mitigation portfolios and macro-economic costs assessed in this report are based on top-down modelling. Most models use a global least-cost approach to mitigation portfolios, with universal emissions trading, assuming transparent markets, no transaction cost, and thus perfect implementation of mitigation measures throughout the 21st century. Costs are given for a specific point in time. Global modelled costs will increase if some regions, sectors (e.g. land use), options or gases are excluded. Global modelled costs will decrease with lower baselines, use of revenues from carbon taxes and auctioned permits, and if induced technological learning is included. These models do not consider climate benefits and generally also co-benefits of mitigation measures, or equity issues. Significant progress has been achieved in applying approaches based on induced technological change to stabilisation studies; however, conceptual issues remain. In the models that consider induced technological change, projected costs for a given stabilisation level are reduced; the reductions are greater at lower stabilisation level.

Table 4.3. Integrating climate change considerations into development policies – selected examples in the area of mitigation. {WGIII 12.2.4.6}

Selected sectors	Non-climate change policy instruments and actions	Potentially affects:
Macro-economy	Implement non-climate taxes/subsidies and/or other fiscal and regulatory policies that promote sustainable development	Total global GHG emissions
Forestry	Adoption of forest conservation and sustainable management practices	GHG emissions from deforestation
Electricity	Adoption of cost-effective renewables, demand-side management programmes, and transmission and distribution loss reduction	Electricity sector CO ₂ emissions
Petroleum imports	Diversifying imported and domestic fuel mix and reducing economy's energy intensity to improve energy security	Emissions from crude oil and product imports
Insurance for building, transport sectors	Differentiated premiums, liability insurance exclusions, improved terms for green products	Transport and building sector GHG emissions
International finance	Country and sector strategies and project lending that reduces emissions	Emissions from developing countries

4.5 International and regional cooperation

There is *high agreement* and *much evidence* that notable achievements of the UNFCCC and its Kyoto Protocol are the establishment of a global response to the climate change problem, stimulation of an array of national policies, the creation of an international carbon market and the establishment of new institutional mechanisms that may provide the foundation for future mitigation efforts. Progress has also been made in addressing adaptation within the UNFCCC and additional initiatives have been suggested. {WGII 18.7; WGIII 13.3, SPM}

The impact of the Protocol's first commitment period relative to global emissions is projected to be limited. Its economic impacts on participating Annex-B countries are projected to be smaller than presented in the TAR, which showed 0.2 to 2% lower GDP in 2012 without emissions trading and 0.1 to 1.1% lower GDP with emissions trading among Annex-B countries. To be more environmentally effective, future mitigation efforts would need to achieve deeper reductions covering a higher share of global emissions (see Topic 5). {WGIII 1.4, 11.4, 13.3, SPM}

The literature provides *high agreement* and *much evidence* of many options for achieving reductions of global GHG emissions at the international level through cooperation. It also suggests that successful agreements are environmentally effective, cost-effective, incorporate distributional considerations and equity, and are institutionally feasible. {WGIII 13.3, SPM}

Greater cooperative efforts to reduce emissions will help to reduce global costs for achieving a given level of mitigation, or will improve environmental effectiveness. Improving and expanding the scope of market mechanisms (such as emission trading, Joint Implementation and Clean Development Mechanism) could reduce overall mitigation costs. {WGIII 13.3, SPM}

Efforts to address climate change can include diverse elements such as emissions targets; sectoral, local, sub-national and regional actions; RD&D programmes; adopting common policies; implementing development-oriented actions; or expanding financing instruments. These elements can be implemented in an integrated fashion, but comparing the efforts made by different countries quantitatively would be complex and resource intensive. {WGIII 13.3, SPM}

Actions that could be taken by participating countries can be differentiated both in terms of when such action is undertaken, who participates and what the action will be. Actions can be binding or non-binding, include fixed or dynamic targets, and participation can be static or vary over time. {WGIII 13.3, SPM}

5

The long-term perspective: scientific and socio-economic aspects relevant to adaptation and mitigation, consistent with the objectives and provisions of the Convention, and in the context of sustainable development

5.1 Risk management perspective

Responding to climate change involves an iterative risk management process that includes both mitigation and adaptation, taking into account actual and avoided climate change damages, co-benefits, sustainability, equity and attitudes to risk. *{WGII 20.9, SPM; WGIII SPM}*

Risk management techniques can explicitly accommodate sectoral, regional and temporal diversity, but their application requires information about not only impacts resulting from the most likely climate scenarios, but also impacts arising from lower-probability but higher-consequence events and the consequences of proposed policies and measures. Risk is generally understood to be the product of the likelihood of an event and its consequences. Climate change impacts depend on the characteristics of natural and human systems, their development pathways and their specific locations. *{SYR 3.3, Figure 3.6; WGII 20.2, 20.9, SPM; WGIII 3.5, 3.6, SPM}*

5.2 Key vulnerabilities, impacts and risks – long-term perspectives

The five ‘reasons for concern’ identified in the TAR are now assessed to be stronger with many risks identified with higher confidence. Some are projected to be larger or to occur at lower increases in temperature. This is due to (1) better understanding of the magnitude of impacts and risks associated with increases in global average temperature and GHG concentrations, including vulnerability to present-day climate variability, (2) more precise identification of the circumstances that make systems, sectors, groups and regions especially vulnerable and (3) growing evidence that the risk of very large impacts on multiple century time scales would continue to increase as long as GHG concentrations and temperature continue to increase. Understanding about the relationship between impacts (the basis for ‘reasons for con-

cern’ in the TAR) and vulnerability (that includes the ability to adapt to impacts) has improved. *{WGII 4.4, 5.4, 19.ES, 19.3.7, TS.4.6; WGIII 3.5, SPM}*

The TAR concluded that vulnerability to climate change is a function of exposure, sensitivity and adaptive capacity. Adaptation can reduce sensitivity to climate change while mitigation can reduce the exposure to climate change, including its rate and extent. Both conclusions are confirmed in this assessment. *{WGII 20.2, 20.7.3}*

No single metric can adequately describe the diversity of key vulnerabilities or support their ranking. A sample of relevant impacts is provided in Figure 3.6. The estimation of key vulnerabilities in any system, and damage implied, will depend on exposure (the rate and magnitude of climate change), sensitivity, which is determined in part and where relevant by development status, and adaptive capacity. Some key vulnerabilities may be linked to thresholds; in some cases these may cause a system to shift from one state to another, whereas others have thresholds that are defined subjectively and thus depend on societal values. *{WGII 19.ES, 19.1}*

The five ‘reasons for concern’ that were identified in the TAR were intended to synthesise information on climate risks and key vulnerabilities and to “aid readers in making their own determination” about risk. These remain a viable framework to consider key vulnerabilities, and they have been updated in the AR4. *{TAR WGII Chapter 19; WGII SPM}*

- **Risks to unique and threatened systems.** There is new and stronger evidence of observed impacts of climate change on unique and vulnerable systems (such as polar and high mountain communities and ecosystems), with increasing levels of adverse impacts as temperatures increase further. An increasing risk of species extinction and coral reef damage is projected with higher confidence than in the TAR as warming proceeds. There is *medium confidence* that approximately 20 to 30% of plant and animal species assessed so far are *likely* to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5°C over 1980-1999 levels. Confidence has increased that a 1 to 2°C increase in global mean temperature above 1990 levels (about 1.5 to 2.5°C above pre-indus-

Key Vulnerabilities and Article 2 of the UNFCCC

Article 2 of the UNFCCC states:

“The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.”

Determining what constitutes “dangerous anthropogenic interference with the climate system” in relation to Article 2 of the UNFCCC involves value judgements. Science can support informed decisions on this issue, including by providing criteria for judging which vulnerabilities might be labelled ‘key’. *{SYR 3.3, WGII 19.ES}*

Key vulnerabilities²⁵ may be associated with many climate-sensitive systems, including food supply, infrastructure, health, water resources, coastal systems, ecosystems, global biogeochemical cycles, ice sheets and modes of oceanic and atmospheric circulation. *{WGII 19.ES}*

More specific information is now available across the regions of the world concerning the nature of future impacts, including for some places not covered in previous assessments. *{WGII SPM}*

²⁵ Key Vulnerabilities can be identified based on a number of criteria in the literature, including magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and ‘importance’ of the impacts.

trial) poses significant risks to many unique and threatened systems including many biodiversity hotspots. Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1 to 3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatisation by corals. Increasing vulnerability of Arctic indigenous communities and small island communities to warming is projected. {SYR 3.3, 3.4, Figure 3.6, Table 3.2; WGII 4.ES, 4.4, 6.4, 14.4.6, 15.ES, 15.4, 15.6, 16.ES, 16.2.1, 16.4, Table 19.1, 19.3.7, TS.5.3, Figure TS.12, Figure TS.14}

- **Risks of extreme weather events.** Responses to some recent extreme climate events reveal higher levels of vulnerability in both developing and developed countries than was assessed in the TAR. There is now higher confidence in the projected increases in droughts, heat waves and floods, as well as their adverse impacts. As summarised in Table 3.2, increases in drought, heat waves and floods are projected in many regions and would have mostly adverse impacts, including increased water stress and wild fire frequency, adverse effects on food production, adverse health effects, increased flood risk and extreme high sea level, and damage to infrastructure. {SYR 3.2, 3.3, Table 3.2; WGI 10.3, Table SPM.2; WGII 1.3, 5.4, 7.1, 7.5, 8.2, 12.6, 19.3, Table 19.1, Table SPM.1}
- **Distribution of impacts and vulnerabilities.** There are sharp differences across regions and those in the weakest economic position are often the most vulnerable to climate change and are frequently the most susceptible to climate-related damages, especially when they face multiple stresses. There is increasing evidence of greater vulnerability of specific groups such as the poor and elderly not only in developing but also in developed countries. There is greater confidence in the projected regional patterns of climate change (see Topic 3.2) and in the projections of regional impacts, enabling better identification of particularly vulnerable systems, sectors and regions (see Topic 3.3). Moreover, there is increased evidence that low-latitude and less-developed areas generally face greater risk, for example in dry areas and megadeltas. New studies confirm that Africa is one of the most vulnerable continents because of the range of projected impacts, multiple stresses and low adaptive capacity. Substantial risks due to sea level rise are projected particularly for Asian megadeltas and for small island communities. {SYR 3.2, 3.3, 5.4; WGI 11.2-11.7, SPM; WGII 3.4.3, 5.3, 5.4, Boxes 7.1 and 7.4, 8.1.1, 8.4.2, 8.6.1.3, 8.7, 9.ES, Table 10.9, 10.6, 16.3, 19.ES, 19.3, Table 19.1, 20.ES, TS.4.5, TS.5.4, Tables TS.1, TS.3, TS.4, SPM}
- **Aggregate impacts.** Compared to the TAR, initial net market-based benefits from climate change are projected to peak at a lower magnitude and therefore sooner than was assessed in the TAR. It is *likely* that there will be higher damages for larger magnitudes of global temperature increase than estimated in the TAR, and the net costs of impacts of increased warming are projected to increase over time. Aggregate impacts have also been quantified in other metrics (see Topic 3.3); for example,

climate change over the next century is *likely* to adversely affect hundreds of millions of people through increased coastal flooding, reductions in water supplies, increased malnutrition and increased health impacts. {SYR 3.3, Figure 3.6; WGII 19.3.7, 20.7.3, TS.5.3}

- **Risks of large-scale singularities.**²⁶ As discussed in Topic 3.4, during the current century, a large-scale abrupt change in the meridional overturning circulation is *very unlikely*. There is *high confidence* that global warming over many centuries would lead to a sea level rise contribution from thermal expansion alone that is projected to be much larger than observed over the 20th century, with loss of coastal area and associated impacts. There is better understanding than in the TAR that the risk of additional contributions to sea level rise from both the Greenland and possibly Antarctic ice sheets may be larger than projected by ice sheet models and could occur on century time scales. This is because ice dynamical processes seen in recent observations but not fully included in ice sheet models assessed in the AR4 could increase the rate of ice loss. Complete deglaciation of the Greenland ice sheet would raise sea level by 7m and could be irreversible. {SYR 3.4; WGI 10.3, Box 10.1; WGII 19.3.7, SPM}

5.3 Adaptation and mitigation

There is *high confidence* that neither adaptation nor mitigation alone can avoid all climate change impacts. Adaptation is necessary both in the short term and longer term to address impacts resulting from the warming that would occur even for the lowest stabilisation scenarios assessed. There are barriers, limits and costs that are not fully understood. Adaptation and mitigation can complement each other and together can significantly reduce the risks of climate change. {WGI 4.ES, TS 5.1, 18.4, 18.6, 20.7, SPM; WGIII 1.2, 2.5, 3.5, 3.6}

Adaptation will be ineffective for some cases such as natural ecosystems (e.g. loss of Arctic sea ice and marine ecosystem viability), the disappearance of mountain glaciers that play vital roles in water storage and supply, or adaptation to sea level rise of several metres²⁷. It will be less feasible or very costly in many cases for the projected climate change beyond the next several decades (such as deltaic regions and estuaries). There is *high confidence* that the ability of many ecosystems to adapt naturally will be exceeded this century. In addition, multiple barriers and constraints to effective adaptation exist in human systems (see Topic 4.2). {SYR 4.2; WGII 17.4.2, 19.2, 19.4.1}

Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt. Reliance on adaptation alone could eventually lead to a magnitude of climate change to which effective adaptation is not possible, or will only be available at very high social, environmental and economic costs. {WGII 18.1, SPM}

²⁶ See glossary

²⁷ While it is technically possible to adapt to several metres of sea level rise, the resources required are so unevenly distributed that in reality this risk is outside the scope of adaptation. {WGII 17.4.2, 19.4.1}

Efforts to mitigate GHG emissions to reduce the rate and magnitude of climate change need to account for inertia in the climate and socio-economic systems. {SYR 3.2; WGI 10.3, 10.4, 10.7, SPM; WGIII 2.3.4}

After GHG concentrations are stabilised, the rate at which the global average temperature increases is expected to slow within a few decades. Small increases in global average temperature could still be expected for several centuries. Sea level rise from thermal expansion would continue for many centuries at a rate that eventually decreases from that reached before stabilisation, due to ongoing heat uptake by oceans. {SYR 3.2, WGI 10.3, 10.4, 10.7, SPM}

Delayed emission reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts. Even though benefits of mitigation measures in terms of avoided climate change would take several decades to materialise, mitigation actions begun in the short term would avoid locking in both long-lived carbon intensive infrastructure and development pathways, reduce the rate of climate change and reduce the adaptation needs associated with higher levels of warming. {WGII 18.4, 20.6, 20.7, SPM; WGIII 2.3.4, 3.4, 3.5, 3.6, SPM}

5.4 Emission trajectories for stabilisation

In order to stabilise the concentration of GHGs in the atmosphere, emissions would need to peak and decline thereafter.²⁸ The lower the stabilisation level, the more quickly this peak and decline would need to occur (Figure 5.1).²⁹ {WGIII 3.3, 3.5, SPM}

Advances in modelling since the TAR permit the assessment of multi-gas mitigation strategies for exploring the attainability and costs for achieving stabilisation of GHG concentrations. These scenarios explore a wider range of future scenarios, including lower levels of stabilisation, than reported in the TAR. {WGIII 3.3, 3.5, SPM}

Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels (Table 5.1 and Figure 5.1). {WGIII 3.5, SPM}

Table 5.1 summarises the required emission levels for different groups of stabilisation concentrations and the resulting equilibrium

CO₂ emissions and equilibrium temperature increases for a range of stabilisation levels

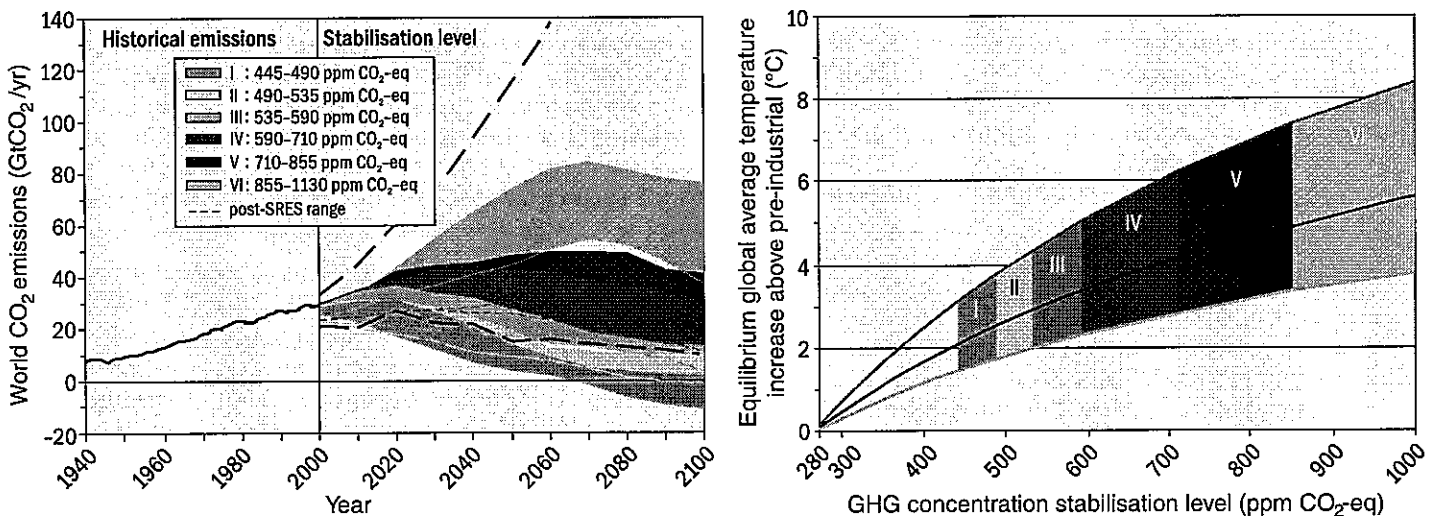


Figure 5.1. Global CO₂ emissions for 1940 to 2000 and emissions ranges for categories of stabilisation scenarios from 2000 to 2100 (left-hand panel); and the corresponding relationship between the stabilisation target and the likely equilibrium global average temperature increase above pre-industrial (right-hand panel). Approaching equilibrium can take several centuries, especially for scenarios with higher levels of stabilisation. Coloured shadings show stabilisation scenarios grouped according to different targets (stabilisation category I to VI). The right-hand panel shows ranges of global average temperature change above pre-industrial, using (i) 'best estimate' climate sensitivity of 3°C (black line in middle of shaded area), (ii) upper bound of likely range of climate sensitivity of 4.5°C (red line at top of shaded area) (iii) lower bound of likely range of climate sensitivity of 2°C (blue line at bottom of shaded area). Black dashed lines in the left panel give the emissions range of recent baseline scenarios published since the SRES (2000). Emissions ranges of the stabilisation scenarios comprise CO₂-only and multigas scenarios and correspond to the 10th to 90th percentile of the full scenario distribution. Note: CO₂ emissions in most models do not include emissions from decay of above ground biomass that remains after logging and deforestation, and from peat fires and drained peat soils. {WGIII Figures SPM.7 and SPM.8}

²⁸ Peaking means that the emissions need to reach a maximum before they decline later.

²⁹ For the lowest mitigation scenario category assessed, emissions would need to peak by 2015 and for the highest by 2090 (see Table 5.1). Scenarios that use alternative emission pathways show substantial differences on the rate of global climate change. {WGII 19.4}

Table 5.1. Characteristics of post-TAR stabilisation scenarios and resulting long-term equilibrium global average temperature and the sea level rise component from thermal expansion only.^a (WGI 10.7; WGIII Table TS.2, Table 3.10, Table SPM.5)

Category	CO ₂ concentration at stabilisation (2005 = 379 ppm) ^b	CO ₂ -equivalent concentration at stabilisation including GHGs and aerosols (2005=375 ppm) ^b	Peaking year for CO ₂ emissions ^{a,c}	Change in global CO ₂ emissions in 2050 (percent of 2000 emissions) ^{a,c}	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity ^{d,e}	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only ^f	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

Notes:

- The emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed here might be underestimated due to missing carbon cycle feedbacks (see also Topic 2.3).
- Atmospheric CO₂ concentrations were 379ppm in 2005. The best estimate of total CO₂-eq concentration in 2005 for all long-lived GHGs is about 455ppm, while the corresponding value including the net effect of all anthropogenic forcing agents is 375ppm CO₂-eq.
- Ranges correspond to the 15th to 85th percentile of the post-TAR scenario distribution. CO₂ emissions are shown so multi-gas scenarios can be compared with CO₂-only scenarios (see Figure 2.1).
- The best estimate of climate sensitivity is 3°C.
- Note that global average temperature at equilibrium is different from expected global average temperature at the time of stabilisation of GHG concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilisation of GHG concentrations occurs between 2100 and 2150 (see also Footnote 30).
- Equilibrium sea level rise is for the contribution from ocean thermal expansion only and does not reach equilibrium for at least many centuries. These values have been estimated using relatively simple climate models (one low-resolution AOGCM and several EMICs based on the best estimate of 3°C climate sensitivity) and do not include contributions from melting ice sheets, glaciers and ice caps. Long-term thermal expansion is projected to result in 0.2 to 0.6m per degree Celsius of global average warming above pre-industrial. (AOGCM refers to Atmosphere-Ocean General Circulation Model and EMICs to Earth System Models of Intermediate Complexity.)

global average temperature increases, using the 'best estimate' of climate sensitivity (see Figure 5.1 for the *likely* range of uncertainty). Stabilisation at lower concentration and related equilibrium temperature levels advances the date when emissions need to peak and requires greater emissions reductions by 2050.³⁰ Climate sensitivity is a key uncertainty for mitigation scenarios that aim to meet specific temperature levels. The timing and level of mitigation to reach a given temperature stabilisation level is earlier and more stringent if climate sensitivity is high than if it is low. (WGIII 3.3, 3.4, 3.5, 3.6, SPM)

Sea level rise under warming is inevitable. Thermal expansion would continue for many centuries after GHG concentrations have stabilised, for any of the stabilisation levels assessed, causing an eventual sea level rise much larger than projected for the 21st century (Table 5.1). If GHG and aerosol concentrations had been stabilised at year 2000 levels, thermal expansion alone would be expected to lead to further sea level rise of 0.3 to 0.8m. The eventual contributions from Greenland ice sheet loss could be several metres, and larger than from thermal expansion, should warming in excess of 1.9 to 4.6°C above pre-industrial be sustained over many centuries. These long-term consequences would have major impli-

cations for world coastlines. The long time scale of thermal expansion and ice sheet response to warming imply that mitigation strategies that seek to stabilise GHG concentrations (or radiative forcing) at or above present levels do not stabilise sea level for many centuries. (WGI 10.7)

Feedbacks between the carbon cycle and climate change affect the required mitigation and adaptation response to climate change. Climate-carbon cycle coupling is expected to increase the fraction of anthropogenic emissions that remains in the atmosphere as the climate system warms (see Topics 2.3 and 3.2.1), but mitigation studies have not yet incorporated the full range of these feedbacks. As a consequence, the emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed in Table 5.1 might be underestimated. Based on current understanding of climate-carbon cycle feedbacks, model studies suggest that stabilising CO₂ concentrations at, for example, 450ppm³¹ could require cumulative emissions over the 21st century to be less than 1800 [1370 to 2200] GtCO₂, which is about 27% less than the 2460 [2310 to 2600] GtCO₂ determined without consideration of carbon cycle feedbacks. (SYR 2.3, 3.2.1; WGI 7.3, 10.4, SPM)

³⁰ Estimates for the evolution of temperature over the course of this century are not available in the AR4 for the stabilisation scenarios. For most stabilisation levels global average temperature is approaching the equilibrium level over a few centuries. For the much lower stabilisation scenarios (category I and II, Figure 5.1), the equilibrium temperature may be reached earlier.

³¹ To stabilise at 1000ppm CO₂, this feedback could require that cumulative emissions be reduced from a model average of approximately 5190 [4910 to 5460] GtCO₂ to approximately 4030 [3590 to 4580] GtCO₂. (WGI 7.3, 10.4, SPM)

5.5 Technology flows and development

There is *high agreement* and *much evidence* that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised in coming decades, assuming appropriate and effective incentives are in place for development, acquisition, deployment and diffusion of technologies and addressing related barriers. *{WGIII SPM}*

Worldwide deployment of low-GHG emission technologies as well as technology improvements through public and private RD&D would be required for achieving stabilisation targets as well as cost reduction.³² Figure 5.2 gives illustrative examples of the contribution of the portfolio of mitigation options. The contribution of different technologies varies over time and region and depends on the baseline development path, available technologies and relative costs, and the analysed stabilisation levels. Stabilisation at the lower of the assessed levels (490 to 540ppm CO₂-eq) requires early investments and substantially more rapid diffusion and commercialisation of advanced low-emissions technologies over the next decades

(2000-2030) and higher contributions across abatement options in the long term (2000-2100). This requires that barriers to development, acquisition, deployment and diffusion of technologies are effectively addressed with appropriate incentives. *{WGIII 2.7, 3.3, 3.4, 3.6, 4.3, 4.4, 4.6, SPM}*

Without sustained investment flows and effective technology transfer, it may be difficult to achieve emission reduction at a significant scale. Mobilising financing of incremental costs of low-carbon technologies is important. *{WGIII 13.3, SPM}*

There are large uncertainties concerning the future contribution of different technologies. However, all assessed stabilisation scenarios concur that 60 to 80% of the reductions over the course of the century would come from energy supply and use and industrial processes. Including non-CO₂ and CO₂ land-use and forestry mitigation options provides greater flexibility and cost-effectiveness. Energy efficiency plays a key role across many scenarios for most regions and time scales. For lower stabilisation levels, scenarios put more emphasis on the use of low-carbon energy sources, such as renewable energy, nuclear power and the use of CO₂ capture and storage (CCS). In these scenarios, improvements of carbon intensity of energy supply and the whole economy needs to be much faster than in the past (Figure 5.2). *{WGIII 3.3, 3.4, TS.3, SPM}*

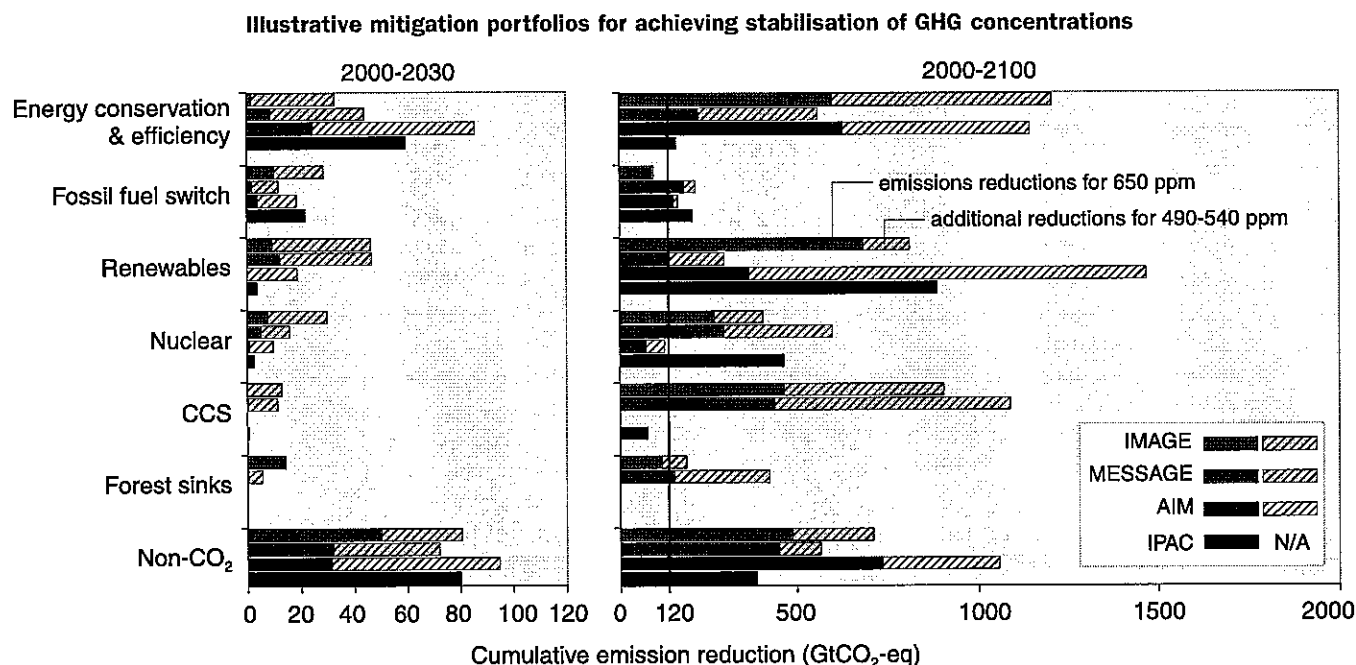


Figure 5.2 Cumulative emissions reductions for alternative mitigation measures for 2000-2030 (left-hand panel) and for 2000-2100 (right-hand panel). The figure shows illustrative scenarios from four models (AIM, IMAGE, IPAC and MESSAGE) aiming at the stabilisation at low (490 to 540ppm CO₂-eq) and intermediate levels (650ppm CO₂-eq) respectively. Dark bars denote reductions for a target of 650ppm CO₂-eq and light bars denote the additional reductions to achieve 490 to 540ppm CO₂-eq. Note that some models do not consider mitigation through forest sink enhancement (AIM and IPAC) or CCS (AIM) and that the share of low-carbon energy options in total energy supply is also determined by inclusion of these options in the baseline. CCS includes CO₂ capture and storage from biomass. Forest sinks include reducing emissions from deforestation. The figure shows emissions reductions from baseline scenarios with cumulative emissions between 6000 to 7000 GtCO₂-eq (2000-2100). *{WGIII Figure SPM.9}*

³² By comparison, government funding in real absolute terms for most energy research programmes has been flat or declining for nearly two decades (even after the UNFCCC came into force) and is now about half of the 1980 level. *{WGIII 2.7, 3.4, 4.5, 11.5, 13.2}*

5.6 Costs of mitigation and long-term stabilisation targets

The macro-economic costs of mitigation generally rise with the stringency of the stabilisation target and are relatively higher when derived from baseline scenarios characterised by high emission levels. {WGIII SPM}

There is *high agreement* and *medium evidence* that in 2050 global average macro-economic costs for multi-gas mitigation towards stabilisation between 710 and 445ppm CO₂-eq are between a 1% gain to a 5.5% decrease of global GDP (Table 5.2). This corresponds to slowing average annual global GDP growth by less than 0.12 percentage points. Estimated GDP losses by 2030 are on average lower and show a smaller spread compared to 2050 (Table 5.2). For specific countries and sectors, costs vary considerably from the global average.³³ {WGIII 3.3, 13.3, SPM}

5.7 Costs, benefits and avoided climate impacts at global and regional levels

Impacts of climate change will vary regionally. Aggregated and discounted to the present, they are *very likely* to impose net annual costs, which will increase over time as global temperatures increase. {WGII SPM}

For increases in global average temperature of less than 1 to 3°C above 1980-1999 levels, some impacts are projected to produce market benefits in some places and sectors while, at the same time, imposing costs in other places and sectors. Global mean losses could be 1 to 5% of GDP for 4°C of warming, but regional losses could be substantially higher. {WGII 9.ES, 10.6, 15.ES, 20.6, SPM}

Peer-reviewed estimates of the social cost of carbon (net economic costs of damages from climate change aggregated across the

globe and discounted to the present) for 2005 have an average value of US\$12 per tonne of CO₂, but the range from 100 estimates is large (-\$3 to \$95/tCO₂). The range of published evidence indicates that the net damage costs of climate change are projected to be significant and to increase over time. {WGII 20.6, SPM}

It is *very likely* that globally aggregated figures underestimate the damage costs because they cannot include many non-quantifiable impacts. It is *virtually certain* that aggregate estimates of costs mask significant differences in impacts across sectors, regions, countries and populations. In some locations and amongst some groups of people with high exposure, high sensitivity and/or low adaptive capacity, net costs will be significantly larger than the global average. {WGII 7.4, 20.ES, 20.6, 20.ES, SPM}

Limited and early analytical results from integrated analyses of the global costs and benefits of mitigation indicate that these are broadly comparable in magnitude, but do not as yet permit an unambiguous determination of an emissions pathway or stabilisation level where benefits exceed costs. {WGIII SPM}

Comparing the costs of mitigation with avoided damages would require the reconciliation of welfare impacts on people living in different places and at different points in time into a global aggregate measure of well-being. {WGII 18.ES}

Choices about the scale and timing of GHG mitigation involve balancing the economic costs of more rapid emission reductions now against the corresponding medium-term and long-term climate risks of delay. {WGIII SPM}

Many impacts can be avoided, reduced or delayed by mitigation. {WGII SPM}

Although the small number of impact assessments that evaluate stabilisation scenarios do not take full account of uncertainties in projected climate under stabilisation, they nevertheless provide indications of damages avoided and risks reduced for different

Table 5.2. Estimated global macro-economic costs in 2030 and 2050. Costs are relative to the baseline for least-cost trajectories towards different long-term stabilisation levels. {WGIII 3.3, 13.3, Tables SPM.4 and SPM.6}

Stabilisation levels (ppm CO ₂ -eq)	Median GDP reduction ^a (%)		Range of GDP reduction ^b (%)		Reduction of average annual GDP growth rates (percentage points) ^{c,e}	
	2030	2050	2030	2050	2030	2050
445 – 535 ^a	Not available		<3	<5.5	< 0.12	< 0.12
535 – 590	0.6	1.3	0.2 to 2.5	slightly negative to 4	< 0.1	< 0.1
590 – 710	0.2	0.5	-0.6 to 1.2	-1 to 2	< 0.06	< 0.05

Notes:

Values given in this table correspond to the full literature across all baselines and mitigation scenarios that provide GDP numbers.

a) Global GDP based on market exchange rates.

b) The 10th and 90th percentile range of the analysed data are given where applicable. Negative values indicate GDP gain. The first row (445-535ppm CO₂-eq) gives the upper bound estimate of the literature only.

c) The calculation of the reduction of the annual growth rate is based on the average reduction during the assessed period that would result in the indicated GDP decrease by 2030 and 2050 respectively.

d) The number of studies is relatively small and they generally use low baselines. High emissions baselines generally lead to higher costs.

e) The values correspond to the highest estimate for GDP reduction shown in column three.

³³ See Footnote 24 for further details on cost estimates and model assumptions.

amounts of emissions reduction. The rate and magnitude of future human-induced climate change and its associated impacts are determined by human choices defining alternative socio-economic futures and mitigation actions that influence emission pathways. Figure 3.2 demonstrates that alternative SRES emission pathways could lead to substantial differences in climate change throughout the 21st century. Some of the impacts at the high temperature end of Figure 3.6 could be avoided by socio-economic development pathways that limit emissions and associated climate change towards the lower end of the ranges illustrated in Figure 3.6. *{SYR 3.2, 3.3; WGIII 3.5, 3.6, SPM}*

Figure 3.6 illustrates how reduced warming could reduce the risk of, for example, affecting a significant number of ecosystems, the risk of extinctions, and the likelihood that cereal productivity in some regions would tend to fall. *{SYR 3.3, Figure 3.6; WGII 4.4, 5.4, Table 20.6}*

5.8 Broader environmental and sustainability issues

Sustainable development can reduce vulnerability to climate change, and climate change could impede nations' abilities to achieve sustainable development pathways. *{WGII SPM}*

It is *very likely* that climate change can slow the pace of progress toward sustainable development either directly through increased

exposure to adverse impacts or indirectly through erosion of the capacity to adapt. Over the next half-century, climate change could impede achievement of the Millennium Development Goals. *{WGII SPM}*

Climate change will interact at all scales with other trends in global environmental and natural resource concerns, including water, soil and air pollution, health hazards, disaster risk, and deforestation. Their combined impacts may be compounded in future in the absence of integrated mitigation and adaptation measures. *{WGII 20.3, 20.7, 20.8, SPM}*

Making development more sustainable can enhance mitigative and adaptive capacities, reduce emissions, and reduce vulnerability, but there may be barriers to implementation. *{WGII 20.8; WGIII 12.2, SPM}*

Both adaptive and mitigative capacities can be enhanced through sustainable development. Sustainable development can, thereby, reduce vulnerability to climate change by reducing sensitivities (through adaptation) and/or exposure (through mitigation). At present, however, few plans for promoting sustainability have explicitly included either adapting to climate change impacts, or promoting adaptive capacity. Similarly, changing development paths can make a major contribution to mitigation but may require resources to overcome multiple barriers. *{WGII 20.3, 20.5, SPM; WGIII 2.1, 2.5, 12.1, SPM}*

6

Robust findings, key uncertainties

Robust findings, key uncertainties

As in the TAR, a robust finding for climate change is defined as one that holds under a variety of approaches, methods, models and assumptions, and is expected to be relatively unaffected by uncertainties. Key uncertainties are those that, if reduced, could lead to new robust findings. [TAR SYR Q.9]

Robust findings do not encompass all key findings of the AR4. Some key findings may be policy-relevant even though they are associated with large uncertainties. [WGII 20.9]

The robust findings and key uncertainties listed below do not represent an exhaustive list.

6.1 Observed changes in climate and their effects, and their causes

Robust findings

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. [WGI 3.9, SPM]

Many natural systems, on all continents and in some oceans, are being affected by regional climate changes. Observed changes in many physical and biological systems are consistent with warming. As a result of the uptake of anthropogenic CO₂ since 1750, the acidity of the surface ocean has increased. [WGI 5.4, WGII 1.3]

Global total annual anthropogenic GHG emissions, weighted by their 100-year GWPs, have grown by 70% between 1970 and 2004. As a result of anthropogenic emissions, atmospheric concentrations of N₂O now far exceed pre-industrial values spanning many thousands of years, and those of CH₄ and CO₂ now far exceed the natural range over the last 650,000 years. [WGI SPM; WGIII 1.3]

Most of the global average warming over the past 50 years is *very likely* due to anthropogenic GHG increases and it is *likely* that there is a discernible human-induced warming averaged over each continent (except Antarctica). [WGI 9.4, SPM]

Anthropogenic warming over the last three decades has *likely* had a discernible influence at the global scale on observed changes in many physical and biological systems. [WGII 1.4, SPM]

Key uncertainties

Climate data coverage remains limited in some regions and there is a notable lack of geographic balance in data and literature on observed changes in natural and managed systems, with marked scarcity in developing countries. [WGI SPM; WGII 1.3, SPM]

Analysing and monitoring changes in extreme events, including drought, tropical cyclones, extreme temperatures and the frequency and intensity of precipitation, is more difficult than for climatic averages as longer data time-series of higher spatial and temporal resolutions are required. [WGI 3.8, SPM]

Effects of climate changes on human and some natural systems are difficult to detect due to adaptation and non-climatic drivers. [WGII 1.3]

Difficulties remain in reliably simulating and attributing observed temperature changes to natural or human causes at smaller than continental scales. At these smaller scales, factors such as land-use change and pollution also complicate the detection of anthropogenic warming influence on physical and biological systems. [WGI 8.3, 9.4, SPM; WGII 1.4, SPM]

The magnitude of CO₂ emissions from land-use change and CH₄ emissions from individual sources remain as key uncertainties. [WGI 2.3, 7.3, 7.4; WGIII 1.3, TS.14]

6.2 Drivers and projections of future climate changes and their impacts

Robust findings

With current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. [WGIII 3.2, SPM]

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emissions scenarios. [WGI 10.3, 10.7, SPM]

Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century. [WGI 10.3, 11.1, SPM]

The pattern of future warming where land warms more than the adjacent oceans and more in northern high latitudes is seen in all scenarios. [WGI 10.3, 11.1, SPM]

Warming tends to reduce terrestrial ecosystem and ocean uptake of atmospheric CO₂, increasing the fraction of anthropogenic emissions that remains in the atmosphere. [WGI 7.3, 10.4, 10.5, SPM]

Anthropogenic warming and sea level rise would continue for centuries even if GHG emissions were to be reduced sufficiently for GHG concentrations to stabilise, due to the time scales associated with climate processes and feedbacks. [WGI 10.7, SPM]

Equilibrium climate sensitivity is *very unlikely* to be less than 1.5°C. [WGI 8.6, 9.6, Box 10.2, SPM]

Some systems, sectors and regions are *likely* to be especially affected by climate change. The systems and sectors are some ecosystems (tundra, boreal forest, mountain, mediterranean-type, mangroves, salt marshes, coral reefs and the sea-ice biome), low-lying coasts, water resources in some dry regions at mid-latitudes and in the dry tropics and in areas dependent on snow and ice melt, agriculture in low-latitude regions, and human health in areas with low adaptive capacity. The regions are the Arctic, Africa, small islands and Asian and African megadeltas. Within other regions, even those with high incomes, some people, areas and activities can be particularly at risk. [WGII TS.4.5]

Impacts are *very likely* to increase due to increased frequencies and intensities of some extreme weather events. Recent events have demonstrated the vulnerability of some sectors and regions, including in developed countries, to heat waves, tropical cyclones, floods and drought, providing stronger reasons for concern as compared to the findings of the TAR. [WGII Table SPM.2, 19.3]

Key uncertainties

Uncertainty in the equilibrium climate sensitivity creates uncertainty in the expected warming for a given CO₂-eq stabilisation scenario. Uncertainty in the carbon cycle feedback creates uncertainty in the emissions trajectory required to achieve a particular stabilisation level. *{WGI 7.3, 10.4, 10.5, SPM}*

Models differ considerably in their estimates of the strength of different feedbacks in the climate system, particularly cloud feedbacks, oceanic heat uptake and carbon cycle feedbacks, although progress has been made in these areas. Also, the confidence in projections is higher for some variables (e.g. temperature) than for others (e.g. precipitation), and it is higher for larger spatial scales and longer time averaging periods. *{WGI 7.3, 8.1-8.7, 9.6, 10.2, 10.7, SPM; WGII 4.4}*

Aerosol impacts on the magnitude of the temperature response, on clouds and on precipitation remain uncertain. *{WGI 2.9, 7.5, 9.2, 9.4, 9.5}*

Future changes in the Greenland and Antarctic ice sheet mass, particularly due to changes in ice flow, are a major source of uncertainty that could increase sea level rise projections. The uncertainty in the penetration of the heat into the oceans also contributes to the future sea level rise uncertainty. *{WGI 4.6, 6.4, 10.3, 10.7, SPM}*

Large-scale ocean circulation changes beyond the 21st century cannot be reliably assessed because of uncertainties in the meltwater supply from the Greenland ice sheet and model response to the warming. *{WGI 6.4, 8.7, 10.3}*

Projections of climate change and its impacts beyond about 2050 are strongly scenario- and model-dependent, and improved projections would require improved understanding of sources of uncertainty and enhancements in systematic observation networks. *{WGII TS.6}*

Impacts research is hampered by uncertainties surrounding regional projections of climate change, particularly precipitation. *{WGII TS.6}*

Understanding of low-probability/high-impact events and the cumulative impacts of sequences of smaller events, which is required for risk-based approaches to decision-making, is generally limited. *{WGII 19.4, 20.2, 20.4, 20.9, TS.6}*

6.3 Responses to climate change

Robust findings

Some planned adaptation (of human activities) is occurring now; more extensive adaptation is required to reduce vulnerability to climate change. *{WGII 17.ES, 20.5, Table 20.6, SPM}*

Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt. *{WGII 20.7, SPM}*

A wide range of mitigation options is currently available or projected to be available by 2030 in all sectors. The economic mitigation potential, at costs that range from net negative up to US\$100/tCO₂-equivalent, is sufficient to offset the projected growth of global emissions or to reduce emissions to below current levels in 2030. *{WGIII 11.3, SPM}*

Many impacts can be reduced, delayed or avoided by mitigation. Mitigation efforts and investments over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels. Delayed emissions reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts. *{WGII SPM, WGIII SPM}*

The range of stabilisation levels for GHG concentrations that have been assessed can be achieved by deployment of a portfolio of technologies that are currently available and those that are expected to be commercialised in coming decades, provided that appropriate and effective incentives are in place and barriers are removed. In addition, further RD&D would be required to improve the technical performance, reduce the costs and achieve social acceptability of new technologies. The lower the stabilisation levels, the greater the need for investment in new technologies during the next few decades. *{WGIII 3.3, 3.4}*

Making development more sustainable by changing development paths can make a major contribution to climate change mitigation and adaptation and to reducing vulnerability. *{WGII 18.7, 20.3, SPM; WGIII 13.2, SPM}*

Decisions about macro-economic and other policies that seem unrelated to climate change can significantly affect emissions. *{WGIII 12.2}*

Key uncertainties

Understanding of how development planners incorporate information about climate variability and change into their decisions is limited. This limits the integrated assessment of vulnerability. *{WGII 18.8, 20.9}*

The evolution and utilisation of adaptive and mitigative capacity depend on underlying socio-economic development pathways. *{WGII 17.3, 17.4, 18.6, 19.4, 20.9}*

Barriers, limits and costs of adaptation are not fully understood, partly because effective adaptation measures are highly dependent on specific geographical and climate risk factors as well as institutional, political and financial constraints. *{WGII SPM}*

Estimates of mitigation costs and potentials depend on assumptions about future socio-economic growth, technological change and consumption patterns. Uncertainty arises in particular from assumptions regarding the drivers of technology diffusion and the potential of long-term technology performance and cost improvements. Also little is known about the effects of changes in behaviour and lifestyles. *{WGIII 3.3, 3.4, 11.3}*

The effects of non-climate policies on emissions are poorly quantified. *{WGIII 12.2}*

Desert Rock Energy Co., PSD Appeal 08-03
Conservation Petitioners' Exhibits

EXHIBIT 49

Ozone Air Quality Analyses in the PSD Permit Application for the Desert Rock Energy Facility

October 25, 2006

Technical Report Prepared By
Jana B. Milford, Ph.D., J.D.

1. The DREF Permit Application Must Include an Adequate Analysis of Ozone Air Quality Impacts

Ozone, the main component of photochemical smog, forms in the lower atmosphere when nitrogen oxides (NOx) and volatile organic compounds (VOCs) react in the presence of sunlight. Because of its serious effects on human health and on vegetation, ozone has been regulated as a criteria pollutant under the Clean Air Act since 1971. In that year, the U.S. Environmental Protection Agency set National Ambient Air Quality Standards for photochemical oxidants, of which ozone is the predominant example.¹ Clean Air Act Part C New Source Review requirements for Prevention of Significant Deterioration of Air Quality apply for ozone in areas that are attaining the current ozone standards.²

The proposed Desert Rock Energy Facility will emit large quantities of NOx and VOC, which are precursors of ozone. The facility is proposed with the potential to emit 3,325 tpy NOx and 166 tpy VOC,³ which exceed EPA's significance level of 40 tpy for both pollutants. Because DREF emissions of NOx and VOC exceed EPA significance levels, an air quality analysis of ozone impacts is required under Section 165(a) of the Clean Air Act.

Section 165(a) provides " No major emitting facility on which construction is commenced after August 7, 1977, may be constructed in any area to which this part applies unless – ...

(6) there has been an analysis of any air quality impacts projected for the area as a result of growth associated with such facility." 42 U.S.C. § 7475(a)(6).

The regulations implementing these provisions are contained at 40 CFR Part 52.21 for federally permitted facilities such as the proposed DREF. These regulations were recently amended to explicitly designate nitrogen oxides (in addition to volatile organic

¹ The designation of the indicator for this standard was changed to ozone in 1979.

² Alabama Power Co. v. Costle, 636 F.2d 323, 406 (D.C. Cir. 1979).

³ EPA Region 9, Ambient Air Quality Impact Report for Desert Rock Energy Project, 5.

compounds) as precursor pollutants for ozone, for which impacts on ambient ozone concentrations must be determined:⁴

§52.21 Prevention of significant deterioration of air quality.

* * * * *

(b) * * *

(1) * * *

(ii) A major source that is major for volatile organic compounds or NO_x shall be considered major for ozone.

* * * * *

(2) * * *

(ii) Any significant emissions increase (as defined at paragraph (b) (40) of this section) from any emissions units or net emissions increase (as defined in paragraph (b) (2) of this section) at a major stationary source that is significant for volatile organic compounds or NO_x shall be considered significant for ozone.

⁴ 70 Fed. Reg. 71612 (Nov. 29, 2005).

(23) (1) * * *

Pollutant and Emissions Rate

* * *

Ozone: 40 tpy of volatile organic compounds or NO_x

* * * * *

(50) * * *

(1) Any pollutant for which a national ambient air quality standard has been promulgated and any constituents or precursors for such pollutants identified by the Administrator (e.g., volatile organic compounds and NO_x are precursors for ozone);

* * * * *

(1) * * *

(5) * * *

(1) * * *

(e) * * *

[footnote 1] No de minimis air quality level is provided for ozone. However, any net emissions increase of 100 tons per year or more of volatile organic compounds or nitrogen oxides subject to PSD would be required to perform an ambient impact analysis, including the gathering of ambient air quality data.

* * * * *

VOC emissions have long been recognized as ozone precursors for PSD purposes, for which ozone impacts analyses are required. The Environmental Appeals Board explained *In Re Masonite* that “[a]lthough VOCs are not regulated under the Act, they are a precursor to the formation of ozone, which is regulated under the Act, and they are therefore treated under the PSD regulations as a proxy for ozone. Thus, the regulations provide that “[a]ny net emissions increase that is significant for volatile organic compounds shall be considered significant for ozone.” 40 C.F.R. § 52.21(b)(2)(ii).”⁵ The EAB further explained

“a permit application for a major modification is required to contain an analysis of ambient air quality in the area that the major stationary source or major modification would affect. 40 C.F.R. § 52.21(m)(1)(i). Such analysis is required for a particular pollutant only if the modification would result in a significant net emissions increase in that pollutant. *Id.* A

⁵ *In Re Masonite Corporation*, PSD Appeal No. 94-1, at 554 (EAB, Nov. 1, 1994).

modification may be exempted from this requirement at the Region's discretion, however, if the net emissions increase of the pollutant would cause air quality impacts less than amounts specified at 40 C.F.R. § 52.21(i)(8). That provision lists ozone but does not specify any amount. However, the listing for ozone in that provision is followed by a footnote, which reads as follows:

No *de minimis* air quality level is provided for ozone. However, any net increase of 100 tons per year or more of volatile organic compounds subject to PSD would be required to perform an ambient impact analysis including the gathering of ambient air quality data.”⁶

In the Masonite case, the net emissions increase at the source was found to be less than 100 tons per year, so ozone modeling was not required. However, DREF emissions of both NO_x and VOC exceed the *de minimis* level of 100 tons per year listed in 40 CFR § 52.21.

2. The Ozone Modeling Referenced in the DREF Permit Application Is Not Adequate to Satisfy the Requirements of Section 165 of the Clean Air Act

The DREF permit application fails to provide the ozone air quality impacts analysis required to satisfy section 165(a)(6) and its implementing regulations. No ozone modeling was performed for this application. Instead, the application cites modeling performed for the San Juan Early Action Ozone Compact (EAC), and claims “based on the results of this study, which accounted for the Project emissions in the region, it can be concluded that the Desert Rock Energy Facility will not cause or contribute to an exceedance of the ozone AAQS in the region.”⁷

The ozone modeling performed for the San Juan Early Action Compact and referenced in the DREF application is inadequate to support the stated conclusion or to satisfy the requirements of section 165(a)(6). The San Juan EAC ozone modeling study applied the photochemical grid model CAMx to simulate historical conditions in the San Juan Basin/Four Corners area in 2002 and to project whether the area would meet the NAAQS for ozone in 2007.⁸ CAMx is an appropriate model for the EAC,⁹ and overall the model performance was deemed adequate for EAC purposes. But the DREF permit application relies on an abbreviated model run performed to test the sensitivity of the projected future ozone levels to emissions from two potential power plants.¹⁰ This sensitivity analysis has several critical deficiencies that render it completely inadequate for the DREF permit application.

⁶ *Id.* at 576.

⁷ ENSR Corporation, Desert Rock Energy Facility Application for Prevention of Significant Deterioration Permit – Class II Area Modeling Update, 6-12, June 2006.

⁸ Environ, Air Quality Modeling Analysis for the San Juan Early Action Ozone Compact: Base Case and Future Case Modeling, Draft Report, January 2004.

⁹ 40 CFR Part 51 App. W., section 5.2.1.

¹⁰ Environ, Air Quality Modeling Analysis for the San Juan Early Action Ozone Compact: Maintenance for Growth and Control Strategy Modeling, Draft Report, February 2004.

The potential power plants considered in the sensitivity analysis are labeled “STEAG” and “Star Lake”; the STEAG plant was intended to represent a plant similar to what is now the DREF proposal.¹¹ But as discussed by Tran (2006),¹² there are critical discrepancies between the modeled plant and the proposed DREF facility, notably including the fact that the modeled plant had NOx emissions of only 1,569 tpy, whereas the proposed DREF plant could emit 3,325 tpy of NOx.

Even if the DREF plant had been accurately represented, the San Juan EAC sensitivity analysis would not be adequate to estimate the ozone impacts of the proposed facility for purposes of section 165(a)(6), because the sensitivity analysis was limited to a short and non-representative period of time. Although the main San Juan EAC ozone modeling (covering the 2002 base case and 2007 future case) was performed for meteorological conditions corresponding to four multi-day episodes of high ozone that occurred in the Farmington NM area from June 4 – July 23, 2002, the sensitivity analysis was limited to a 4-day episode, from June 5 – 8, 2002. (The first day included in the sensitivity analysis model run, June 4, is used as an initialization day. The results for this first day of modeling are expected to be too sensitive to uncertain initial conditions to be reliable, and are disregarded.) Even if the DREF’s emissions had been represented accurately, this brief episode is not long enough to represent the air quality impacts of the plant on the surrounding area.

As discussed in the report on the base and future-case modeling,¹³

Synoptic winds over the San Juan Basin are westerly to southwesterly throughout much of the year. At night, local drainage flows can override the synoptic winds, producing locally channeled flows aligned along the San Juan River drainage and other terrain features. Indeed, the east-west orientation of the San Juan River as it leaves Navajo Reservoir induces a high frequency of west and east winds when measured at the Bloomfield monitor. There is also evidence at the Bloomfield monitor of nocturnal drainage flows off the elevated terrain to the north.

The DREF will be located southwest of Farmington, NM. Hence it is critical to examine the impacts of the plant when winds are from the Southwest, which is the predominant case for synoptic winds. Yet as described in the base case modeling report, winds on two of the four days considered in the June 4 – 8 episode were from completely different directions:¹⁴

¹¹ *Id.*

¹² Tran, K. Comments on the Air Quality and Visibility Impact Analyses of the PSD Permit Application for the Desert Rock Energy Facility, AMI Environmental, October 5, 2006.

¹³ Environ, Air Quality Modeling Analysis for the San Juan Early Action Ozone Compact: Base Case and Future Case Modeling, 2-2, Draft Report, January 2004.

¹⁴ *Id.* at 2-3.

2.2.2 Episode 1: 4-8 June 2002

The 4-8 June 2002 episode occurred on Tuesday through Saturday. The highest 8-hr ozone levels recorded at Substation and Bloomfield during the 5-8 June period were 76 and 80 ppb respectively. During this period, the Substation monitor recorded three days wherein the peak 8-hr ozone values were close to the current 2001-2003 Design Value of (74.7 ppb). These were 75 ppb, 77 ppb, and 76 ppb on 5, 7, and 8 June respectively. A peak 8-hour ozone concentration of 80 ppb was measured at Bloomfield on 5 June ozone levels at this site dropped considerably for the rest of the period.

Back trajectories calculated using the NOAA HYSPLIT model for each day of the 4-8 June '02 period indicate that the episode includes three distinct synoptic scale transport patterns (i.e., three different meteorological regimes) all occurring within a single multiple-day episode. On the 5th, wind transport at the ground and aloft is from the north, veering to the northeast as the air parcels enter the Farmington region. Winds at the surface and at 100m appear to come down the Animas river drainage from the Durango area while the aloft winds on the 5th have more northerly path. On the following day, a transition in synoptic transport conditions is evident. Surface and low level (i.e., 100m) flows come from the southeast whereas aloft, the wind are northerly and northwesterly. The synoptic transition is stabilized on the 7th and 8th of June where the winds at the ground and aloft come from the southwest—the predominant synoptic flow direction for historically high 8-hr ozone concentrations in San Juan County.

Thus at best, the sensitivity analysis included only two days when the DREF was even upwind of the impact area of greatest concern.

The base case modeling report further indicates that model performance was inadequate on June 5, the day during the modeling period when observed ozone concentrations in the Farmington area peaked. As shown in Table 3-4 of the base case report (inserted below), the peak observed concentration on June 5 was 80.6 ppb, whereas the maximum modeled concentration was 67.7 ppb.¹⁵ As noted in Environ's report on the base case and future case modeling, the normalized bias for that day, -16.0 %, is outside the range EPA deems to be adequate performance. Although substandard performance statistics on a single day like this were not considered disqualifying for purposes of the Early Action Compact because model performance was deemed adequate overall, the bias on this day is obviously more important in the context of the shorter time period considered in the sensitivity analysis on which DREF's application attempts to rely.

¹⁵ *Id.* at 3-13.

Table 3-4. CAMx 8-hr Ozone Model Evaluation Results for San Juan EAC Episodes 1-4: Four Corners Analysis Domain.

Four Corners Analysis Region														
Date	Day	ATS	FB	FE	AU	A-MEAN	N. Bias	Bias	N. Error	Error	Var	Max. O	Max. P	
04-Jun	155	-19.7	-7.2	12.5	7.9	16.4	-14.8	-8.6	21.1	11.4	112.6	65.0	70.1	
05-Jun	156	-26.1	-11.4	14.5	-16.1	17.6	-16.0	-10.3	22.3	13.2	113.7	80.6	67.7	
06-Jun	157	-21.1	-0.3	9.4	-2.2	14.8	0.7	-1.0	19.2	10.2	137.3	69.9	68.3	
07-Jun	158	-23.0	5.7	16.1	-1.8	25.2	1.2	-1.1	21.8	11.6	191.6	77.1	75.8	
08-Jun	159	-26.0	-7.2	16.4	-4.3	19.7	-10.6	-8.1	22.0	13.4	159.9	76.8	73.4	
16-Jun	167	-19.2	-4.6	9.1	-4.4	14.0	-7.3	-5.3	18.1	10.4	94.8	73.8	70.5	
17-Jun	168	-24.5	-7.2	8.7	-2.2	13.0	-7.8	-5.7	17.3	10.4	98.2	80.4	78.6	
18-Jun	169	-16.2	-0.1	7.4	11.7	12.2	-1.6	-2.0	17.5	9.8	112.8	75.1	83.9	
19-Jun	170	-21.3	-8.1	10.6	-5.0	16.3	-5.5	-4.8	20.7	12.3	145.4	77.5	73.6	
30-Jun	181	2.0	6.6	6.8	12.9	11.3	-3.9	-2.7	17.3	8.9	132.5	64.3	72.5	
01-Jul	182	-19.1	-8.5	9.5	3.9	13.9	-20.8	-11.4	24.4	13.0	92.2	64.4	66.9	
02-Jul	183	-29.1	-11.3	12.2	-16.7	20.1	-19.6	-12.6	21.9	13.7	121.6	78.8	65.6	
16-Jul	197	-27.3	-4.1	10.9	-8.7	19.7	-16.5	-9.4	24.0	12.8	155.8	70.3	64.1	
17-Jul	198	-19.7	-4.1	9.4	-10.2	17.0	-17.6	-10.6	25.2	14.2	145.9	74.5	66.9	
18-Jul	199	-29.0	-5.5	9.7	-15.8	13.6	-12.7	-7.9	20.3	11.5	151.6	79.2	66.7	
Average		-21.3	-4.5	10.9	-3.4	16.3	-10.2	-6.8	20.9	11.8	131.0	73.8	71.0	

The San Juan EAC sensitivity analysis results are deeply flawed as estimates of the ozone air quality impacts of the DREF. Even if the results are considered at face value, however, they raise significant concerns. The model results indicate that in conjunction with a second new power plant (the "Star Lake" facility), a new power plant emitting half as much NOx as the DREF facility could increase daily maximum 8-hour ozone concentrations in the surrounding area by up to 2 ppb. As shown in Table 4-1 of the sensitivity analysis report, this increase is much larger than that associated with any other sensitivity analysis scenario considered in the San Juan EAC modeling, including substantially accelerated oil and gas development and doubling all the anthropogenic area source emissions in the region.¹⁶

Table 4-1. Maximum 8-hr Ozone (ppb) Relative to 2007 Base Case Simulation.

Date	Base '07	Run 5: Add EGUs		Run 6: Oil & Gas		Run 7: Motor V.		Run 8: Bio x2		Run 10: Area S x2	
	Max O3	Max O3	Max Inc.	Max O3	Max Inc.	Max O3	Max Inc.	Max O3	Max Inc.	Max O3	Max Inc.
4 Jun '07	63.20	63.20	0.9011	63.20	0.0001	63.23	0.1380	64.61	1.7800	63.24	0.0580
5 Jun '07	64.62	64.61	0.5157	64.69	-0.0137	64.66	0.3321	67.31	3.3530	64.74	0.3448
8 Jun '07	66.64	66.54	1.9930	66.62	-0.0384	66.62	0.1858	71.07	5.8220	66.66	0.0370
7 Jun '07	66.63	66.67	1.2400	66.59	-0.0345	66.82	0.1686	73.75	7.7830	66.81	0.3433
Average	65.77	65.76	1.1025	65.73	-0.0216	65.83	0.2136	69.19	4.6345	65.86	0.1958
Max	66.63	66.67	1.9930	66.59	0.0001	66.82	0.3321	73.75	7.7830	66.81	0.3448

¹⁶ Environ, Air Quality Modeling Analysis for the San Juan Early Action Ozone Compact: Maintenance for Growth and Control Strategy Modeling, 4-6, Draft Report, February 2004.

- > **Run 5: Power Plants:** Two additional electric generating units (EGUs) were added to the existing power plants assumed to be in operation in 2007 (e.g., Four Corners, San Juan, Mustang). These new units were the STEAG and Star Lake EGUs;
- > **Run 6: Oil and Gas:** This emission scenario involved modifying the year 2007 inventory for oil and gas production in the San Juan Basin to reflect accelerated growth and development of the field, reflective of estimated emissions in the year 2012 instead;
- > **Run 7: On Road Motor Vehicles:** On-road mobile source emissions in several counties in the Four Corners region were scaled up to reflect an older vehicle fleet compared to the national default assumptions used in the 2007 baseline modeling. Described by Mansell (2004), these national defaults were derived from a MOBILE6 sensitivity analysis performed by the Federal Highway Administration (Tang, et al., 2003);
- > **Run 8: Biogenic Emissions:** Biogenic VOC and NOx emissions were doubled over the 4 km modeling domain relative to the year 2007 baseline assumptions in order to provide an upper bound estimate of the impact on 8-hr ozone that might result from uncertainty in quantifying ozone precursor emissions from natural sources; and
- > **Run 10: Area Source Emissions Uncertainty:** Anthropogenic area source VOC and NOx emissions were doubled over the 4 km modeling domain relative to the year 2007 baseline assumptions in order to provide an upper bound estimate of the impact on 8-hr ozone that might result from uncertainty in modeled ozone impacts from area sources. Note that emissions from natural sources, EGUs, and oil and gas sources were unchanged from 2007 baseline conditions in this scenario.

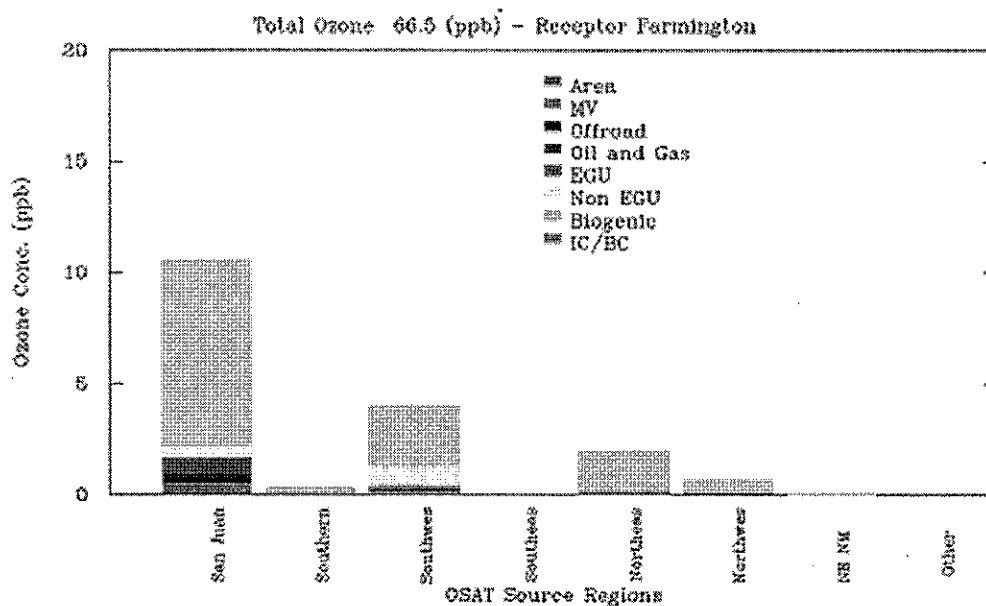
The DREF application cites the San Juan EAC study as indicating “background ozone (transported from long distances) is an important contributor to elevated ozone levels” and “biogenic emissions contribute more to ozone formation than anthropogenic sources.”¹⁷ These statements are problematic, because there is evidence that the source apportionment tool used in the San Juan EAC modeling study overestimates the contribution from long-range transport,¹⁸ and because interactions between biogenic and anthropogenic sources mean they cannot be logically separated (biogenic emissions would form insignificant ozone if anthropogenic emissions were absent). But if the “conclusions” cited in the DREF application are taken at face value, these statements only serve to underscore the significance of the estimated impact of the additional power plant emissions. The results to which the DREF application refers are illustrated by those presented below for Farmington, NM on June 7, which are presented as Figure 3-3(g) in the sensitivity analysis report.¹⁹ These results are based on application of the Ozone Source Apportionment Technology (OSAT) to the CAMx model runs. They suggest that most of the ozone modeled at Farmington is coming from boundary or initial conditions (these contributions are not shown in the figures) or from biogenic emissions (vegetation) within the modeling domain. But if the ozone “contributed” by boundary conditions

¹⁷ ENSR Corporation, Desert Rock Energy Facility Application for Prevention of Significant Deterioration Permit – Class II Area Modeling Update, 6-12, June 2006.

¹⁸ Dunker, A., Yarwood, G., Ortmann, J., Wilson, G. (2002) Comparison of source apportionment and source sensitivity of ozone in a three-dimensional air quality model, *Environ. Sci. Technol.*, 36: 2953-2964.

¹⁹ Environ, Air Quality Modeling Analysis for the San Juan Early Action Ozone Compact: Maintenance for Growth and Control Strategy Modeling, 3-19, Draft Report, February 2004.

(e.g., ozone coming into the model domain from the Pacific Ocean) and the ozone “contributed” by biogenic emissions from vegetation are not counted, the maximum contributions from the new power plants shown in Table 4-1 from the sensitivity analysis report are seen to be quite large in comparison to the contributions from other potentially controllable sources in the region.



(g) Farmington

As noted above, the statement in the DREF modeling update report that “biogenic emissions contribute more to ozone formation than anthropogenic sources” is problematic. This statement is deeply misleading because biogenic emissions alone would produce little or no ozone. Vegetation emits significant quantities of VOC, but little NOx. Biogenic VOC produce ozone only in conjunction with nitrogen oxides, which are largely of anthropogenic origin – as from the proposed DREF power plant. In fact, many biogenic VOCs react directly with ozone, and in the absence of significant NOx emissions tend to destroy ozone and “clean up” the atmosphere. This was demonstrated nearly 20 years ago in a 1987 article by Dr. Michael Trainer and his colleagues at the National Atmospheric and Oceanic Administration.²⁰

The Ozone Source Apportionment Technology (OSAT) tool in CAMx that was used to perform source attribution for the San Juan EAC modeling is highly misleading in its treatment of biogenic VOCs. The OSAT tool attributes ozone production to VOCs or NOx based on an incremental limiting condition – i.e., whether ozone production at a particular point and time would be most sensitive to an incremental reduction in VOC or

²⁰ Trainer, M., E.T. Williams, D.D. Parrish, M.P. Buhr, E.J. Allwine, H.H. Westberg, F.C. Fehsenfeld and S.C. Liu (1987) Models and observations of the impact of natural hydrocarbons on rural ozone, *Nature*, 329:705-707.

NOx concentration at that point. This approach is misleading because it places the “blame” entirely on the limiting precursor, even though both VOCs and NOx are required for ozone to accumulate. Moreover, as stated in the CAMx User’s Guide, OSAT is of limited value in predicting responses to emissions controls because of the non-linear nature of the ozone formation process.²¹ To address some of the limitations of the original OSAT approach, CAMx also provides the Anthropogenic Precursor Culpability Assessment (APCA) attribution option. APCA more appropriately allocates ozone production that is due to the combination of biogenic VOCs and anthropogenic NOx to the controllable, anthropogenic NOx emissions. EPA used the APCA option, not the OSAT tool used in the San Juan EAC analysis, in the source attribution studies it conducted in preparation for issuing the Clean Air Interstate Rule.²²

3. The Ozone Modeling Referenced in the DREF Permit Application Is Not Adequate to Satisfy the Overarching Purposes of the Clean Air Act’s PSD Provisions

The purposes of the Prevention of Significant Deterioration Provisions of the Clean Air Act go beyond simply ensuring that attainment areas do not cross the line to nonattainment status. Section 160 states the purposes of this part of the Act as

- (1) to protect public health and welfare from any actual or potential adverse effect which in the Administrator’s judgment may reasonably be anticipated to occur, ... notwithstanding attainment and maintenance of all national ambient air quality standards;
- (2) to preserve, protect, and enhance the air quality in national parks, national wilderness areas, ...;
- (3) to insure that economic growth will occur in a manner consistent with the preservation of existing clean air resources;
- (4) to assure that emissions from any source in any State will not interfere with any portion of the applicable implementation plan to prevent significant deterioration for any other State; and
- (5) to assure that any decision to permit increased air pollution in any area ... is made only after careful evaluation of all the consequences of such a decision and after adequate procedural opportunities for informed public participation in the decisionmaking process.²³

Section 166(a) requires EPA to promulgate additional regulations to prevent the significant deterioration of air quality which would result from hydrocarbons, carbon monoxide, photochemical oxidants [ozone], and nitrogen oxides, which regulations are to “fulfill the goals and purposes set forth in section 7401 and 7470 [160] of this title”²⁴ and “provide specific measures at least as effective as the increments established in section

²¹ CAMx v4.10s User’s Guide, August 2004.

²² EPA (2004) Technical Support Document for the Interstate Air Quality Rule Air Quality Modeling Analyses, January.

²³ 42 U.S.C. § 7470.

²⁴ 42 U.S.C. § 7476(c).

7473 [for particulate matter and sulfur dioxide].”²⁵ EPA has never promulgated the required regulations for photochemical oxidants or ozone, but this failure on the part of the agency does not obviate its obligation to ensure that permits issued under Part C satisfy the purposes of the Prevention of Significant Deterioration provisions. Consequently, the contribution that emissions from the DREF facility make to ozone levels in the surrounding area must be evaluated for their impact in degrading air quality and harming human health and the environment, not just whether or not they push the Farmington area over the existing NAAQS.²⁶ This obligation is particularly critical in this case, because a compelling body of scientific evidence indicates that the existing NAAQS is not adequate to protect human health.

On August 25, 2006, in response to evidence compiled in the Criteria Document for EPA’s current review of the adequacy of the existing ozone standard,²⁷ the Clean Air Scientific Advisory Committee (CASAC) voted to recommend that the NAAQS for ozone be tightened to no more than 70 ppb, on an eight-hour average basis.²⁸ The CASAC is established in the Clean Air Act with the specific charge of advising the EPA Administrator on air quality standards.²⁹ The CASAC’s recommendation was formally transmitted to the Administrator in a letter dated October 24, 2006.³⁰ In their letter, CASAC says “There is no scientific justification for retaining the current primary 8-hr NAAQS of 0.08 parts per million (ppm). The primary 8-hr NAAQS needs to be substantially reduced to protect human health, particularly in sensitive subpopulations. *Therefore, the CASAC unanimously recommends a range of 0.060 to 0.070 ppm for the primary ozone NAAQS.*”³¹ The letter adds “we note that the understanding of the associated science has progressed to the point that *there is no longer significant scientific uncertainty regarding the CASAC’s conclusion that the current 8-hr primary NAAQS must be lowered.*”³²

CASAC’s recommendation follows the action taken by the California Air Resources Board in April 2005, when it lowered California’s state ozone standard to 0.070 ppm for an eight-hour averaging period, not to be exceeded.³³

²⁵ 42 U.S.C. § 7476(d).

²⁶ Environmental Defense Fund v. EPA, 898 F.2d 183, 190 (D.C. Cir. 1990).

²⁷ U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). E-14, U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-05/004aF-cF, 2006.

²⁸ “Air Pollution Tighter Air Quality Standard for Ozone Recommended by EPA Advisory Panel”, BNA News, August 28, 2006.

²⁹ 42 U.S.C. § 7409(d).

³⁰ R. Henderson, Clean Air Scientific Advisory Committee’s (CASAC) Peer Review of the Agency’s 2nd Draft Ozone Staff Paper, available at <http://www.epa.gov/sab/fiscal07.htm>.

³¹ *Id.* Emphasis in original.

³² *Id.* Emphasis in original.

³³ The U.S. EPA recently concluded “evidence from newer epidemiologic studies supports the 1996 O₃ AQCD [Air Quality Criteria Document] conclusions that children are more likely at increased risk for O₃-induced health effects. Notably, epidemiologic studies have indicated adverse respiratory health outcomes associated with O₃ exposure in children. In addition, recently published epidemiologic studies also suggest that older adults (aged >65 years) appear to be at excess risk of O₃-related mortality or hospitalization. U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). E-22, U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-05/004aF-cF, 2006.

Breathing ozone at concentrations close to or above the level of the current standard, 0.08 ppm, can cause a suite of adverse health effects, including decreased lung function, particularly in children active outdoors; increased airway responsiveness, and inflammation of the lungs.³⁴ Epidemiological studies show that elevated ozone concentrations are associated with increased numbers of hospital admissions and emergency room visits for respiratory problems in children and adults with preexisting respiratory diseases such as asthma, and with increased mortality rates.³⁵ Two large studies in the United States and Europe recently linked total mortality, cardiovascular mortality and respiratory mortality to short term increases in ozone levels.³⁶

Children are particularly at risk of adverse respiratory effects from breathing ozone because their lungs are not fully developed and so their airways are narrow, and their respiration rates are higher than those of adults in relation to their size.³⁷ Studies conducted in recent years have linked ozone with school absences resulting from sore throats, coughs, and asthma attacks; decreased lung function in girls with asthma; and long-term lung damage in children.³⁸ A recent study demonstrated that children who use maintenance medication for asthma had an increased likelihood of wheezing and chest tightness when ozone levels increased.³⁹ One major study associated exposure to ozone with the onset of asthma in children not previously diagnosed with asthma.⁴⁰

In addition to its effects on human health, ozone also has serious effects on the natural environment. Plants are even more sensitive to ozone than are humans. Ozone damage to plants includes visible injury to leaves, premature leaf loss, reduced photosynthesis, and reduced growth.⁴¹ Ozone pollution costs the agricultural industry millions of dollars each

³⁴ U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Fact Sheet: Health and Environmental Effects of Ground-Level Ozone, July 17, 1997; American Lung Association, Ozone Air Pollution: What Are Its Health Effects? (available at www.lungusa.org/air/envozone.html).

³⁵ *Id.*

³⁶ Bell, M.L.; McDermott, A.; Zeger, S.L.; Samet, J.M.; Dominici, F. (2004) Ozone and Short-term Mortality in 95 US Urban Communities, 1987-2000. *J. American Medical Association*, 292:2372-2378; Gryparis, A. et al. (2004) Acute Effects of Ozone on Mortality from the "Air Pollution and Health a European Approach" Project. *Am. J. Respir. Crit. Care Med.* 170: 1080-1087.

³⁷ U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Fact Sheet: Health and Environmental Effects of Ground-Level Ozone, July 17, 1997; American Lung Association, Ozone Air Pollution: What Are Its Health Effects? available at www.lungusa.org/air/envozone.html.

³⁸ F.D. Gilliland et al., The Effects of Ambient Air Pollution on School Absenteeism Due to Respiratory Illnesses, *Epidemiology* 12 (2001): 43-54; L. Chen et al., Elementary School Absenteeism and Air Pollution, *Inhalation Toxicology* 12 (2000): 997-1016; J.M. Peters et al., A Study of Twelve Southern California Communities with Differing Levels and Types of Air Pollution, *American Journal of Respiratory and Critical Care Medicine* 159 (1999): 768-775; T. Frischer et al., Lung Function Growth and Ambient Ozone: A Three-Year Population Study in School Children, *American Journal of Respiratory and Critical Care Medicine* 160 (1999): 390-396.

³⁹ Gent, J.F., et al. (2003) Association of low level ozone and fine particles with respiratory symptoms in children with asthma, *J. American Medical Association* 290: 1859-1867.

⁴⁰ McConnell, R., et al. (2002) Asthma in exercising children exposed to ozone: a cohort study, *Lancet* 359: 386-391.

⁴¹ National Park Service (2002) Air Quality in the National Parks, 2d. ed., September.

year in decreased crop yields.⁴² In its new Criteria Document for ozone, the U.S. EPA concludes “data published since 1996 continues [sic] to support and strengthen the conclusions of previous O₃ AQCDs [Air Quality Criteria Documents] that there is strong evidence that current ambient O₃ concentrations cause (1) decreased growth and biomass accumulation in annual, perennial and woody plants, including agronomic crops, annuals, shrubs, grasses, and trees; (2) decreased yield and/or nutritive quality in a large number of agronomic and forage crops; and (3) impaired aesthetic quality of many native plants and trees by increased foliar injury.”⁴³ Due to the toxic effects of ozone on native plants, ozone is prominently discussed as a pollutant that impacts air quality related values in the Federal Land Managers’ Air Quality Related Values Workgroup Phase I Report (December 2000).⁴⁴

To satisfy the purposes of the Clean Air Act’s PSD provisions, the DREF permit application must include ozone modeling that accurately represents the expected emissions from the facility, and examines the impacts of ozone on human health and on vegetation in the surrounding area. For purposes of the human health impacts analysis, contributions to ozone concentrations that are capable of causing adverse effects, “notwithstanding attainment and maintenance of all national ambient air quality standards”⁴⁵ must be considered. The scientific evidence and recommendations reached by the Clean Air Science Advisory Committee indicate that the relevant range for concentrations of health concern extends below 0.070 ppm on an eight-hour average basis.

The base case and future case modeling report prepared for the San Juan Early Action Compact indicates that projected 2007 ozone design values were above 0.070 ppm at multiple monitors in the Farmington area.⁴⁶ Although as discussed above the sensitivity analyses performed for the Early Action Compact modeling were inadequate to assess the impact of the DREF in relation to the projected 2007 ozone design values, there is evidence in the base case and future case modeling that DREF contributions could exacerbate ozone levels that are capable of causing adverse health effects.

This report was prepared by Jana Milford, Ph.D., J.D., an environmental engineer with more than 20 years experience in air quality modeling, focusing on chemistry and transport modeling for secondary air pollutants such as ozone. Dr. Milford currently works half-time as an Associate Professor of Mechanical Engineering at the University of

⁴² U.S. EPA, Fact Sheet: *Health and Environmental Effects of Ground-Level Ozone*, available at <http://www.epa.gov/ttn/oarpg/naaqsfm/o3health.html> (last visited July 1, 2003); National Acid Precipitation Assessment Program, NAPAP Biennial Report to Congress: An Integrated Assessment, 63 (Silver Spring, MD: May 1998).

⁴³ U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). E-28, U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-05/004aF-cF, 2006.

⁴⁴ Available at <http://www2.nature.nps.gov/air/Pubs/pdf/flag/FlagFinal.pdf>.

⁴⁵ 42 U.S.C. § 7470(1).

⁴⁶ Environ, Air Quality Modeling Analysis for the San Juan Early Action Ozone Compact: Base Case and Future Case Modeling, 5-4, Table 5-1, Draft Report, January 2004.

Colorado at Boulder, and half-time as a senior scientist and attorney with the non-partisan, non-profit group Environmental Defense. A copy of Dr. Milford's curriculum vitae is attached.

ATTACHMENT 1

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Education

J.D., University of Colorado School of Law, May 2004.

Registered attorney in Colorado, October 2004 to present.

Ph.D., Engineering and Public Policy, Carnegie Mellon University, May 1988.

Thesis: Photochemical Air Pollution Control Strategy Development. (Advisor: G.J. McRae)

M.S., Civil Engineering, Carnegie Mellon University, May 1985.

Thesis: The Sizes of Particulate Trace Elements in the Atmosphere. (Advisor: C.I. Davidson)

B.S., with distinction, Engineering Science, Iowa State University, May 1983.

Professional History

Associate Professor (part time since August 2003), Department of Mechanical Engineering and Environmental Engineering Program, University of Colorado at Boulder, August 1997 - present.

Senior Scientist and Staff Attorney (part time), Environmental Defense, May 2004 – present.

Director, Environmental Engineering Program, University of Colorado at Boulder, June 1998 - July 2001.

Assistant Professor, Department of Mechanical Engineering, University of Colorado at Boulder, January 1994 - July 1997.

Assistant Professor, Department of Civil Engineering and Environmental Research Institute, University of Connecticut, September 1989 - December 1993.

Faculty-in-Residence, Washington Internships for Students of Engineering (American Society for Engineering Education), summer 1990.

Congressional Fellow and Analyst, Office of Technology Assessment, United States Congress, September 1987 - July 1989.

Research and Teaching Assistant, Carnegie Mellon University, 1983 - 1987.

Engineering Intern, General Motors Corporation, 1983.

Teaching Experience

Quantitative Methods for Policy Analysis, with R. Pielke, Jr., University of Colorado at Boulder (graduate, spring 2005).

Thermodynamics, University of Colorado at Boulder (undergraduate, fall 2004, fall 2006).

Computational Methods, University of Colorado at Boulder (undergraduate, spring 2004).

Environmental Modeling, University of Colorado at Boulder (graduate, fall 1999, fall 2003, spring 2006).

Methods of Engineering Analysis I, University of Colorado at Boulder (graduate, fall 1998).

Introduction to Research, University of Colorado at Boulder (graduate, fall 1996, fall 1997, spring 2001).

Engineering Projects, University of Colorado at Boulder (freshman design course, spring 1996, spring 1997, spring 1998, fall 2000, fall 2005).

Special Topics: Air Quality Modeling, University of Colorado at Boulder (graduate, spring 1997).

Air Pollution Control Engineering, University of Colorado at Boulder (undergraduate/graduate, fall 1994, fall 1995, fall 1996, spring 1998, spring 2000).

Heat Transfer, University of Colorado at Boulder (undergraduate, spring 1994, spring 1995, spring 1996).

Air Quality Modeling, University of Connecticut (graduate, spring 1993).

Civil Engineering Projects, University of Connecticut (senior design course, spring 1993).

Fundamentals of Environmental Engineering, University of Connecticut (undergraduate, fall 1991, fall 1992, fall 1993).

Transport and Transformation of Air Pollution, University of Connecticut (graduate, spring 1990, spring 1991, spring 1992).

Analysis of Civil Engineering Systems, University of Connecticut (undergraduate, fall 1990).

Numerical Methods, University of Connecticut, with D. Ahlfeld, N. Nikolaidis (graduate, fall 1990).

Atmospheric Chemistry, University of Connecticut (professional development, fall 1990).

Consulting Experience

Professional consulting on air quality modeling, alternative fuels and environmental policy for: Baker and Hostetler, LLP; Croker, Huck & Assoc., P.C.; California Air Resources Board; Congressional Office of Technology Assessment; Grand Canyon Visibility Transport Commission; Montana Environmental Information Center; the National Renewable Energy Laboratory; and the U.S. Environmental Protection Agency.

State and National Service

U.S. Environmental Protection Agency, Science Advisory Board, December 2005 to present.

National Academy of Engineering, Committee on Energy Futures and Air Pollution in Urban China and the United States, February 2005 to present.

Environmental Science and Technology, Editorial Advisory Board, November 2002 to January 2006.

National Academy of Sciences, Committee on Air Quality Management in the United States, member, May 2001 to January 2004.

U.S. Environmental Protection Agency, Science Advisory Board, National Air Toxics Assessment Subcommittee, consultant, March 2001.

U.S. Environmental Protection Agency, Science Advisory Board, Environmental Models Subcommittee, consultant, May 1998 to present.

Department of Engineering and Public Policy, Carnegie Mellon University, Advisory Board, October 1993 to present.

U.S. Environmental Protection Agency, Science Advisory Board, Radiation Advisory Committee, consultant for Advisory on GENII, April 2000.

U.S. Environmental Protection Agency, Science Advisory Board, Air Toxics Monitoring Strategy Subcommittee, consultant, March 2000.

U.S. Environmental Protection Agency, Board of Scientific Counselors, Fine Particulate Matter Research Strategy Review Committee, October 1999.

California Air Resources Board, Reactivity Scientific Advisory Committee, April 1996 to May 2000.

North American Research Strategy for Tropospheric Ozone, facilitator for the NARSTO Science Symposium, West Palm Beach, FL, November 17-19, 1997.

Colorado Air Quality Control Commission, appointed April 1994 by Governor Roy Romer, vice-chairperson, June 1996 to May 1997.

Denver Metropolitan Area Blueprint for Clean Air (long-range air quality planning process) steering committee member, June 1996 to May 1997.

U.S. Environmental Protection Agency, North American Research Strategy for Tropospheric Ozone, science team member, January 1994 to December 1997.

Air and Waste Management Association, International Conference on Regional Photochemical Measurement and Modeling Studies, San Diego, CA, November 1993, session co-chair.

Transportation Research Board, National Cooperative Highway Research Program, Project on Improving Transportation Inputs for Air Quality Modeling, panel member, May 1993 to June 1995.

New England Board of Higher Education, Council of Academic Advisors on Environmental Sciences and Engineering, 1993.

American Lung Association of Connecticut, Clean Air Advisory Committee, 1993.

U.S. Environmental Protection Agency, review of Clean Air Act Section 182(f) guidance, 1992-1993.

U.S. Environmental Protection Agency, External Review Committee, ROMNET II project, 1992.

“How Land Disposal and Burning of Demolition Wood Affect the Environment,” report prepared for the Connecticut General Assembly under Public Act 90-264, 1990.

Northeast States for Coordinated Air Use Management/U.S. Environmental Protection Agency/Environment Canada, Symposium on Nitrogen Oxides and Oxidants, program chair, September 1989 to May 1990.

Atmospheric Environment, Environmental Science and Technology, Geophysical Research Letters, The International Journal of Water, Air and Soil Pollution, Journal of the Air & Waste Management Association, Journal of Geophysical Research, National Research Council, Risk Analysis, reviewer.

U.S. Department of Energy, U.S. Environmental Protection Agency, National Aeronautics and Space Administration, National Science Foundation, proposal reviewer and panel member.

Department, College, and University Service

External Review Committee for Multicultural Engineering Program, Chair, College of Engineering and Applied Science, November 2005.

Mechanical Engineering Faculty Search Committee, 2004-2005, 2005-2006.

Mechanical Engineering ABET Committee, 2004-2005.

Boulder Campus Planning Commission, September 2002 to September 2005.

Center for Science and Technology Policy, University of Colorado at Boulder, faculty affiliate, September 2002 to present.

University of Colorado at Boulder, search committee for dean of the College of Engineering and Applied Science, 2000-2001.

University of Colorado at Boulder, Boulder Faculty Assembly, 1999 to 2001.

Department of Mechanical Engineering, graduate committee, 1999 to 2001.

Department of Mechanical Engineering, personnel committee, 1999-2000.

Department of Mechanical Engineering, undergraduate committee, 1994 to 1999.

College of Engineering and Applied Science, Women in Engineering Program, faculty advisory board member, 1997 to 1999.

University of Colorado at Boulder, Environmental Program Advisory Committee, 1998 to 2004.

University of Colorado at Boulder, Administrative Streamlining Project Steering Committee, faculty representative, 1998-1999.

Center for Combustion and Environmental Research, member, 1994 to present.

Fellowships and Awards

Faculty Leadership Advancement Group, invited participant, College of Engineering and Applied Science, University of Colorado at Boulder, 2006.

Mechanical Engineering, University of Colorado at Boulder, Distinguished Achievement Award, 2004-2005.

Order of the Coif, University of Colorado School of Law, May 2004.

University of Colorado, Emerging Leaders Program, invited participant, 2002-2003.

Max S. Peters Faculty Service Award, College of Engineering and Applied Science, University of Colorado at Boulder, 2001.

Congressional Fellow, Office of Technology Assessment, 1987 – 1988.

Tau Beta Pi Fellow, Carnegie Mellon University, 1983 – 1984.

Richard King Mellon Fellow, Carnegie Mellon University, 1983 – 1984.

Publications

Textbook

Ramaswami, A., Milford, J.B., Small, M.S., *Integrated Environmental Modeling: Pollutant Transport, Fate and Risk in the Environment*, John Wiley and Sons, 2005.

Congressional Testimony

Friedman, R.M., Milford, J.B., Rapoport, R.D., testimony before the Subcommittee on Oversight and Investigations of the Energy and Commerce Committee, U.S. House of Representatives, July 17, 1989.

Published Monographs

National Research Council of the National Academies, *Air Quality Management in the United States*, The National Academies Press, Washington, DC, January 2004, contributor.

U.S. Congress, Office of Technology Assessment, *Changing by Degrees: Steps to Reduce Greenhouse Gases*, OTA-0-482, Washington, DC, February 1991, contributor.

U.S. Congress, Office of Technology Assessment, *Replacing Gasoline: Alternative Fuels for Light-Duty Vehicles*, OTA-E-364, Washington, DC, September 1990, contributor.

U.S. Congress, Office of Technology Assessment, *Catching Our Breath: Next Steps for Reducing Urban Ozone*, OTA-0-412, Washington, DC, July 1989, coauthor.

Law Review Article

Milford, J.B., "Tribal Authority Under the Clean Air Act: How Is It Working?" *Natural Resources Journal*, **44**:213-242, 2004.

Peer-Reviewed Journal Articles

Helmig, D., Ortega, J., Duhl, T., Tanner, D., Guenther, A., Harley, P., Wiedinmyer, C., Milford, J., Sakulyanontvittaya, T., "Sesquiterpene Emissions from Pine Trees – Identifications, Emission Rates and Flux Estimates for the Contiguous United States," submitted.

Brinkman, G., Vance, G., Hannigan, M., Milford, J.B., "Use of Synthetic Data to Evaluate Positive Matrix Factorization as a Source Apportionment Tool for PM_{2.5} Exposure Data," *Environmental Science and Technology*, **40**:1892-1901, 2006.

Henderson, D., Milford, J.B., Miller, S.L., "Prescribed Burns and Wildfires in Colorado: Impacts of Mitigation Measures on Indoor Air Particulate Matter," *J. Air & Waste Management Association*, **55**:1516-1526, 2005.

Hakami, A., Harley, R.A., Milford, J.B., Odman, M.T., Russell, A.G., "Regional, three-dimensional assessment of the ozone formation potential of organic compounds" *Atmospheric Environment*, **38** (1):121-134, 2004.

Martien, P.T., Harley, R.A., Milford, J.B., Russell, A.G., "Evaluation of Incremental Reactivity and Its Uncertainty in the South Coast Air Basin," *Environmental Science and Technology*, **37**:1598-1608, 2003.

Miller, S.L., Anderson, M.J., Daly, E.P., Milford, J.B., "Source Apportionment of Exposures to Volatile Organic Compounds, I. Evaluation of Receptor Models Using Simulated Exposure Data," *Atmospheric Environment*, **36**:3629-3641, 2002.

- Anderson, M.J., Daly, E.P., Miller, S.L., Milford, J.B. "Source Apportionment of Exposures to Volatile Organic Compounds, II. Application of Receptor Models to TEAM Study Data," *Atmospheric Environment*, **36**:3643-3658, 2002.
- Wang, L., Milford, J.B., Carter, W.P.L. "Analysis of Chamber-Derived Incremental Reactivity Estimates for N-Butyl Acetate and 2-Butoxy Ethanol," *Atmospheric Environment*, **36**:115-135, 2002.
- Anderson, M., Miller, S.L., Milford, J.B., "Source Apportionment of Exposure to Toxic Volatile Organic Compounds Using Positive Matrix Factorization," *International Journal of Exposure Analysis and Environmental Epidemiology*, **11**:295-307, 2001.
- Wang, L., Milford, J.B., "Reliability of Optimal Control Strategies for Photochemical Air Pollution," *Environmental Science and Technology*, **35**:1173-1180, 2001.
- Wang, L., Milford, J.B., Carter, W.P.L. "Reactivity Estimates for Aromatic Compounds: 1. Uncertainty in Chamber-Derived Parameters," *Atmospheric Environment*, **34**:4337-4348, 2000.
- Wang, L., Milford, J.B., Carter, W.P.L. "Reactivity Estimates for Aromatic Compounds: 2. Uncertainty in Incremental Reactivities", *Atmospheric Environment*, **34**:4349-4360, 2000.
- Bergin, M.S., Milford, J.B. "Application of Bayesian Monte Carlo Analysis to a Lagrangian Photochemical Air Quality Model," *Atmospheric Environment*, **34**:781-792, 2000.
- Bergin, M.S., Noblet, G.S., Petrini, K., Dhieux, J.R., Milford, J.B., Harley, R.A. "Formal Uncertainty Analysis of a Lagrangian Photochemical Air Pollution Model," *Environmental Science and Technology*, **33**:1116-1126, 1999.
- Das, M., Milford, J.B. "Factors Influencing Ozone Chemistry in Subsonic Aircraft Plumes," *Atmospheric Environment*, **33**:869-880, 1999.
- Bergin, M.S., Russell, A.G., Milford, J.B., "Effects of Chemical Mechanism Uncertainties on the Reactivity Quantification of Volatile Organic Compounds Using a Three-Dimensional Air Quality Model," *Environmental Science and Technology*, **32**:694-703, 1998.
- Kuhn, M., Builtjes, P.J.H., Poppe, D., Simpson, D., Stockwell, W.R., Andersson-Skoeld, Y., Baart, A., Das, M., Fiedler, F., Hov, O., Kirchner, F., Makar, P.A., Milford, J.B., Roemer, M.G.M., Ruhnke, R., Strand, A., Vogel, B., Vogel, H. "Intercomparison of the Gas-Phase Chemistry in Several Chemistry and Transport Models," *Atmospheric Environment*, **32**:693-709, 1998.
- Harley, R.A., Sawyer, R.F., Milford, J.B. "Updated Photochemical Modeling for California's South Coast Air Basin: Comparison of Chemical Mechanisms and Motor Vehicle Emission Inventories," *Environmental Science and Technology*, **31**:2829-2839, 1997.
- Gao, D., Stockwell, W.R., Milford, J.B. "Global Uncertainty Analysis of a Regional Scale Gas-Phase Chemical Mechanism," *J. Geophysical Research*, **101**:9107-9119, 1996.
- Yang, Y-J, Stockwell, W.R., Milford, J.B., "Effect of Chemical Product Yield Uncertainties on Reactivities of VOCs and Emissions from Reformulated Gasolines and Methanol Fuels," *Environmental Science and Technology*, **30**:1392-1397, 1996.
- Yang, Y-J, Milford, J.B., "Quantification of Uncertainty in Reactivity Adjustment Factors from Reformulated Gasolines and Methanol Fuels," *Environmental Science and Technology*, **30**:196-203, 1996.

- Bergin, M.S., Russell, A.G., Milford, J.B., "Quantification of Individual VOC Reactivity Using a Chemically Detailed, Three-Dimensional Photochemical Model," *Environmental Science and Technology*, **29**:3029-3037, 1995.
- Gao, D., Stockwell, W.R., Milford, J.B. "First Order Sensitivity and Uncertainty Analysis for a Regional-Scale Gas-Phase Chemical Mechanism," *J. Geophysical Research*, **100**:23153-23166, 1995.
- Russell, A.G., Milford, J.B., Bergin, M.S., McBride, S., McNair, L., Yang, Y-J, Stockwell, W.R., Croes, B. "Urban Ozone Control and Atmospheric Reactivity of Organic Gases," *Science*, **269**: 491-495, 1995.
- Stockwell, W.R., Milford, J.B., Gao, D., Yang, Y-J, "The Effect of Acetyl Peroxy - Peroxy Radical Reactions on Peroxyacetyl Nitrate and Ozone Concentrations," *Atmospheric Environment*, **29**:1591-1599, 1995.
- Yang, Y-J, Stockwell, W.R., Milford, J.B., "Uncertainties in Incremental Reactivities of Volatile Organic Compounds," *Environmental Science and Technology*, **29**:1336-1345, 1995.
- Lin, C., Milford, J.B., "Decay-Adjusted Chemical Mass Balance Receptor Modeling for Volatile Organic Compounds," *Atmospheric Environment*, **28**:3261-3276, 1994.
- Milford, J.B., Gao, D., Zafirakou, A., Pierce, T.E., "Ozone Precursor Levels and Responses to Emissions Reductions: Analysis of Regional Oxidant Model Results," *Atmospheric Environment*, **28**:2093-2104, 1994.
- Milford, J.B., Gao, D., Sillman, S., Blossey, P., Russell, A.G., "NO_y as an Indicator of the Sensitivity of Ozone to ROG and NO_x Emissions," *J. Geophysical Research*, **99**:3533-3542, 1994.
- Milford, J.B., Gao, D., Russell, A.G., McRae, G.J., "Comparing the Sensitivities of Condensed Chemical Mechanisms for Photochemical Air Pollution," *Environmental Science and Technology*, **26**:1179-1189, 1992.
- Russell, A.G., St. Pierre, D., Milford, J.B., "Ozone Control and Methanol Fuel Use," *Science*, **247**:201-205, 1990.
- Milford, J.B., Russell, A.G., McRae, G.J., "Spatial Patterns in Photochemical Pollutant Response to NO_x and ROG Reductions," *Environmental Science and Technology*, **23**:1290-1301, 1989.
- McRae, G.J., Milford, J.B., Slompak, B.J., "Changing Roles for Supercomputing in Chemical Engineering," *International J. Supercomputing Applications*, **2**:16-40, 1988.
- Stockwell, W.R., Milford, J.B., McRae, G.J., Middleton, P., Chang, J.S., "Nonlinear Coupling in the NO_x - SO_x - Reactive Organic System," *Atmospheric Environment*, **22**:2481-2490, 1988.
- Hahn, R.W., McRae, G.J., Milford, J.B., "Coping with Complexity in the Design of Environmental Policy," *J. Environmental Management*, **27**:109-125, 1988.
- Milford, J.B., Davidson, C.I., "The Sizes of Particulate Sulfate and Nitrate in the Atmosphere: A Review," *J. Air Pollution Control Association*, **37**:125-134, 1987.
- Milford, J.B., Davidson, C.I., "The Sizes of Particulate Trace Elements in the Atmosphere: A Review," *J. Air Pollution Control Association*, **35**:1249-1260, 1985.